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PRACTICAL CROP PROTECTION

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PRACTICAL CROP PROTECTION

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PREFACE

During the past decade, media attention has increasingly focused on pesticide issues. These issues include residues in food, ground water contamination, wildlife damage, habitat loss and bystander exposure. Some of these problems can be dealt with by improved practices in the use and handling of pesticides. In other cases a reduction in the use of some pesticides may be the only answer. They cannot be dismissed as "things we need to educate the public about."

In the United States of America, 10 per cent of community wells and four per cent of private wells contain some contamination from at least one pesticide. Canadian data are less complete. However, we know contamination in Alberta is much less than in the United States. This book is dedicated to keeping it that way, while providing commercial farmers with practical, economical solutions to pest problems.

Another concern is the erosion of large areas of farmland by excessive and incorrect tillage practices. Erosion is also linked to poor crop rotations and practices such as summer fallow that leave the soil surface exposed without vegetative cover.

While pesticides and tillage are essential production tools, we now know that overuse of either causes problems. The issues

listed above are directly related to current pest control practices. Future practices will require new methods used together to obtain control. These methods must be environmentally sound and sustainable.

Many farmers have expressed an interest in reducing or eliminating the use of chemical pesticides in crop production. Some are concerned about pesticide costs or exposure. Other farmers wish to take advantage of a developing market for "organic" foods. Whatever their reasons, farmers wishing to control weeds, insects and diseases by integrated management techniques require more information. These methods require a detailed knowledge of the pest, its life cycle and its weaknesses that may be exploited for control purposes. Chemicals can be used to retrieve a situation where pests are out of control. Non-chemical methods must rely on prevention if they are to be successful. Proper crop selection, cultural practices and rotations are of cardinal importance.

General principles are reviewed in the introductory part of the text while details on controlling specific pests follow in each appropriate section.

INTRODUCTION

This book is about solutions to weed, insect and disease problems associated with large scale prairie agriculture. The emphasis is on a sustainable approach to integrate many or all control measures into a profitable operation.

Many books on “integrated pest management”, “alternative agriculture” or “organic agriculture” seem to focus on small scale farms with practices closer to gardening than to the large scale production practised on the Prairies. We have focused on the commercial producer and emphasize an approach applicable to large-scale operations.

Our approach is not organic, pro-pesticide, anti-pesticide, anti-tillage or anti-fertilizer. We favor a common sense approach to all of the above and embrace the use of crop rotations, preventive measures, biological control, and careful selection of resistant varieties or immune crop species to control pest buildup. Good agronomic practice in fertility, seeding technique, row spacing, plant populations and use of well-adapted varieties will help to establish strong plants that can withstand pest damage and compete with weeds. Pesticides should be used as needed with care and attention. Do not rely on pesticides as the only control. Proper application of cultural, biological and chemical controls are more cost effective and will be less likely to damage beneficial species.

In modern agriculture, good farm practices are combined with good government and community programs. Because seed cleaning plants are expensive, it does not make sense for every farmer to own one. Biological control requires that agents be collected, screened and made available by governments. Integrated pest control in today’s world includes techniques that operate on a larger scale than a single farm unit. Decisions about which control techniques may be used have also moved beyond the farm level. Regulation often determines which control may be used. Regulation may also be the only way to achieve uniform, effective control of some pests. In other cases, co-operation between neighbors will be most effective. Increasingly the control decision is determined by regulators and most importantly - **by the consumer**. A variety of methods are required to prevent pest buildup, slow or stop the development of resistant pests and still allow efficient large-scale production.

In the 1990s, pest controls must be effective, safe, environmentally sound and sustainable. Of course they must also be economically viable.

This book provides a broad strategy for pest management and techniques for managing specific pests. To apply an integrated approach requires an understanding of the underlying concepts of pest management, knowledge of appropriate techniques and the ability to adapt those techniques to unique situations.

Basic Concepts

There are thousands of species of plants and animals in Alberta. Most are beneficial, some are occasional pests and a few are always in conflict with human interests.

It is not desirable to destroy plants and animals unless they are causing or likely to cause damage. However, most pest control operations kill many non-target organisms. Tillage, pesticides and even crop rotations kill non-target species. Any habitat change will kill or displace many species. Lethal control is often unavoidable, but we do need to be careful about what we kill accidentally. Destruction of the predators and parasites of our pests can cause a resurgence of the pest in numbers even greater than before. This is why application of broad spectrum pesticides has been described as a pesticide treadmill. This term refers to the treatment of pests and the accidental mortality of their predators. The pest population usually recovers faster than its predators and another pesticide application is required. This may cause a reoccurring need to apply pesticides to the point where the pest eventually develops a resistance to the pesticide.

Fortunately, there are many practices that decrease non-target mortality. We can use less pesticide, apply pesticides at times when beneficial organisms are less vulnerable, use more specific pesticides and apply pesticides only when necessary. This will also save money and delay the development of resistant pests. Integrating the use of pesticides with cultural and biological controls in a planned, systematic approach is known as I.P.M. or Integrated Pest Management.

With attention currently focused on the adverse effects of chemicals we must remain aware that any control measure can have adverse effects. Tillage makes soil vulnerable to erosion. Resistant varieties may produce a lower yield or a less desirable product (in the absence of pests). The farmer must constantly balance short-term versus long-term considerations, cash flow versus long-term profits and other considerations. Recently, better tools have been developed to assist in making these decisions.

The concept of **threshold populations** helps producers decide when pests have increased to a level where control measures are economically justified. **Field scouting techniques** have been developed to measure pest populations so that threshold tables may be used. Better field guides enable producers to easily **identify pest species**. New publications for identification of **beneficial species** are being developed. Finally, better **record keeping systems** are now available. This book describes these tools in detail.

Integrated Pest Management

Many pest control programs rely on the use of chemical pesticides. The normal procedure is to identify pests in the field, estimate the potential damage and decide whether to apply a pesticide. This process fails to anticipate pest buildup or understand why the pest buildup occurs. Broad spectrum insecticides, for example, may also damage populations of beneficial species, contributing to the development of secondary infestations of the original pest species and occasionally, different pest species.

Integrated management considers the overall management of a pest species, not just the control measures used during destructive outbreaks. Indeed the objective is to prevent the pest outbreaks from ever occurring.

Integrated pest management combines chemical, biological, mechanical and cultural controls together in a production system. Preventive measures and treatments are employed as needed. Treatments are not employed on a scheduled basis but are used only in response to the situation identified during pest monitoring. The treatments are selected for least disruption of the natural environment because natural pest control agents often provide the best and certainly the cheapest form of pest control.

In Alberta we often overlook what is probably our most important natural method of pest control - severe weather. Many pests cannot survive Alberta winters. Consequently, we have many fewer pests than our southern neighbors. Farmers can exploit this natural control to a larger degree by making a few management changes. Similarly, our dry climate protects our crops from many disease organisms. Throughout this book we will refer to many control practices designed to take advantage of our weather. A few examples are:

- cooling stored grain to kill insects,
- fall tillage to expose weed roots to freeze-drying over winter,
- tillage conducted in hot, dry weather to deprive weeds of moisture and disrupt their normal growth.

Integrated pest control systems involve not only monitoring pest populations but also attempting to understand why the pests are there. Perhaps the crop rotation presents the pest an opportunity or maybe the most resistant variety is not being used. How did those new weeds get on your farm in the first place? Maybe the cause was you. In addition to simply controlling pests when they appear, the farmer using I.P.M. must constantly monitor, plan and analyze. This requires a good knowledge of pest biology and trends. To analyze trends, we must have data; a I.P.M. program requires the farmer to keep different and more extensive records than has been the custom.

Record keeping is time consuming and repetitive. Its value is often not immediately apparent. Unlike spraying or other control measures it does not seem urgent, so to ensure it is done at all it must be planned. As you begin to keep detailed production records you will notice different responses to planting dates, fertilizer input, disease, herbicides, previous crops in the rotation and other practices. The pest situation in a field or on

a farm is usually based on events of the previous or earlier growing seasons. The combination of events and treatments are too complex to remember without the help of written records. Recorded, organized information is more reliable and complete than relying upon memory. It can also be analyzed by outside resource people. We suggest you consider using a record keeping system, either manual or electronic, to ease the job of collecting, organizing, and analyzing records.

Creating a set of field records requires that data be gathered in an organized way and that you know what to look for. Start by recording all operations and treatments on a field by field basis. Include fertilization, crop kind and variety, tillage, pesticide applications, etc. Supplement this information with observations and measurements that you take and record. Rainfall, hail storms, floods and other natural events will be part of the record. Finally you will conduct specific operations in the field. This will include an overview to check for seeding or fertilizer misses, soil problems, wind row effects, erosion, patchiness or other patterns. Next you will check in detail for weeds, insect damage, sick or dying plants and you will identify and record pests present and their densities. The field scouting chapter has detailed directions on how to do this.

Pest populations may develop resistance after repeated exposure to an effective control measure: naturally resistant pests are left to repopulate the area each time a control is used. After many generations the entire pest population can become resistant. In other cases a natural or induced mutation can occur in which the mutant is entirely or partly resistant to the control. This type of resistance is difficult to predict because it occurs at random. Resistance is not a unique response to pesticides. Pests either develop resistance or partial resistance to an effective practice or the pest will decline or become extinct. In all cases, however, resistance in pests must be combated through a strategy of rotating control practices, preferably unrelated practices.

The use of resistant varieties combined with crop rotation, foliar fungicides, seed treatment and tillage to bury infected crop residue, in combination or rotation, can prevent disease buildup.

WEED PREVENTION

Preventive control involves all measures taken to forestall the introduction and spread of weeds. Although preventive measures will reduce infestations, no program can eliminate the wide variety of weed species on a given piece of land. Success of a preventive program varies with the weed species and the amount and constancy of effort that you devote to prevention.

Weed Sanitation

Scentless chamomile is present in about 80 per cent of Alberta municipalities. However, through a combination of sanitizing techniques, some municipalities are chamomile free. They accomplished it through the persistent application of some basic principles:

- The sanitation process started when the weed was not present in the municipality or when there were only several small infestations.
- Complete control and subsequent monitoring and control continued on the infested sites for up to ten years after the original infestation.
- Extensive awareness campaigns were launched to alert residents to the potential problem. Incentives were provided to landowners to report the problem rather than hide it. Information was disseminated by newspaper articles, letter stuffers, booths at local fairs and other forms of publicity.
- Scentless chamomile may be elevated to the "restricted" list within a municipality, providing the municipality with the authority to destroy any known site.
- Since the major source of chamomile seed is forage seed, the awareness and control measures were targeted at users of forage seed, producer's right-of-ways, managers, pipeline operators, and others.
- In areas near irrigation canals and other water bodies, a campaign of picking, bagging and disposal through incineration or land filling occurred.
- All control operations scheduled to occur before the onset of seed production.

Preventive programs can also be implemented on an individual farm, and can start with several basic steps:

Weed Free Seed

Any weedy plant in a seed field poses the risk that some weed seeds will find their way into the crop-seed supply even with the best cleaning techniques. However, the

more effective the cleaning technique, the less the potential for infestation.

A 1986 - 1989 weed survey in Alberta identified the sources of seed used by the average producer.

Table 4. Source of seed used by farmers for various crops

Crop grown	Farmer %	Other grower %	Seed agent %	Elevator company %	Seed unknown %
Wheat	73	12	11	4	3
Barley	62	21	15	3	1
Canola	10	6	41	27	18
Oats	53	35	11	1	-
Fall rye	-	67	-	33	-

The greatest potential source of weed seeds comes from seed that is not inspected. The sources of these seeds are "home grown" and "other farmers". Alberta has a good record of sanitation because 98 per cent of this seed was subsequently cleaned at a co-op seed cleaning plant (64%) a private commercial plant (15%), on farm (6%), or in the local elevator (6%). With the exception of the "on-farm" and the elevator system, which are primarily designed for dockage removal, the available cleaning systems remove the majority of weed seeds.

Pedigreed seed, while not weed free, comes with a certificate of analysis that identifies the species and number of weed seeds found in a seed sample. Seed dealers must supply a certificate to buyers upon request. An example of the seed standards is shown in Table 5. The higher the grade, the fewer weed seeds allowed.

Table 5. Maximum number of weed seeds for 500 grams of crop seed

		Total weed seeds	Total other crops
Canada Registered	#1	3	2
Canada Registered	#2	6	4
Canada Certified	#1	3	4
Canada Certified	#2	6	10
Canada Common	#1	10	25
Canada Common	#2	20	50

These standards apply to barley, buckwheat, lentils, lupine, rye, sainfoin, etc. With minor variations, they also apply to wheat, canola, flax, and oats.

Prevent Weed Seed Formation

A weed can produce a few hundred to several thousand seeds depending on the species and the growing conditions. These seeds add to the soil seed bank and will cause problems for producers. Table 6 outlines the number of weed seeds that

can be prevented from entering the soil through timely removal of weeds.

Table 6. Seed production capacities of selected weeds

Common name	Approximate number of seeds per plant
Barnyard grass	7,200
Chickweed, common	12,000
Buckwheat, wild	1,200
Chamomile, scentless	200,000+
Foxtail, green	34,000
Kochia	14,600
Lamb's-quarters	72,000
Medic, black	2,300
Mustard, wild	2,000 -3,500
Oats, wild	250
Pigweed, broadleaf	117,000
Plantain, broadleaf	36,000
Purslane	52,000
Shepherd's-purse	38,500
Smartweeds	3,000
Sow thistle	10,000
Spurge, leafy	250
Thistle, Canada	700

Stevens, O. A. 1932. American J. Botany 19:784-794.

Prevention of seed production is an important control strategy. Mowing some weeds is an effective control; however, other weeds with different growth habits are only slightly affected by mowing and simply continue to flower and produce seeds below the height of the mower. Tillage of fallow fields must be conducted before seed production. Extremely weedy crops can be cut for forage before the weeds go to seed. If viable seeds exist, the feed should be put up for silage because seed viability is usually destroyed in the ensiling process.

Practise Fence Line and Headland Control

Fence lines and headlands serve as habitat for beneficial insects and wildlife. Disturbing these sites may not be necessary as long as they do not act as a refuge for weeds or insect pests. If fence lines, headlands and roadsides are sources of infestation, try planting them with native plants and grasses that are adapted to our climate and growing conditions, and thus are competitive with weeds. Mowing or grazing uncultivated wastelands helps to control weeds. If possible, delay mowing or intensive grazing until late July, to allow ground nesting birds to raise their broods.

Prevent Spread With Soil and Equipment

Weed seeds and vegetative parts of plants move with farm equipment and soil. Long distance transport is responsible for the introduction of new weeds to previously clean areas. Industrial equipment, seed and used farm machinery are the worst offenders. Equipment should be cleaned before moving from one area to another. Place a tarp over grain and soil when it is transported. In addition to preventing weed spread,

tarps reduce unnecessary loss of a valuable product.

Table 7 shows the net loss of grain and associated weed seeds after a three-ton truck travelled 10 km at 80 km/hour.

Table 7. Loss of grain while in transport

Method of box cover	Crop	Net loss	
		lb	Bushels
Full tarp	Barley	0	0
Level box with baffle	Barley	95	2.0
Level box only	Barley	825	17.2
Level box with baffle	Oats	95	3.0
Level box only	Oats	745	23.2
Level box with baffle	Canola	160	3.2
Level box only	Canola	1,125	22.5

Prevent Spread Through Feed and Manure

Weed seeds may remain viable after passing through animals, resulting in contaminated manure. Screenings used for feed should be finely ground, cooked or pelleted to ensure destruction of all the weed seeds. Poultry are most effective in destroying weed seeds as their crops grind the seeds. In order of decreasing effectiveness are sheep, horses, swine, and cattle, as shown in Table 8.

Table 8. Viability of weeds seeds after passing through livestock

Weed	Percentage of viable seed passed by				
	Calves	Horses	Sheep	Hogs	Chickens
Field bindweed	22	6	9	21	0
Sweet clover	14	15	5	16	0
Smartweed	0	0	2	0	0
Peppergrass	5	20	8	3	0

Harmon and Klien, 1934. J. American Soc. Agron. 26(9):762-767.

Once in manure, however, the rate of breakdown depends on the type of weed seed and the temperature of the manure. If the manure is frozen or cold, the seed will live longer.

Table 9. Effect of length of time in cow manure upon the viability of various weed seeds

Kind of seeds	% Viability before burial	% Viability after storage (months)			
		1	2	3	4
Field bindweed	84	4	22	1	0
Sweet clover	68	22	4	0	0
Pepperweed	34	0	0	0	0
Smooth dock	86	0	0	0	0
Smartweed	0	0	0	0	0

Harmon and Klien, 1934. J. American Soc. Agron. 26(9):762-767.

Handling New Weeds in Your Fields

- Have the weed identified by a professional.
- Prevent seed production by removing the plant and seed

head. Bag and bury viable seed or destroy the seed through incineration.

- If the plant is a perennial, destroy the root system by physical, chemical or mechanical means. Use cutting (discs) rather than tearing (cultivator) equipment on perennial weeds to prevent root spread to areas that are not infested.
- Check infestation sites before harvest to insure no more seed has set.
- Monitor sites for three to four years to avoid re-infestation from vegetative parts or seed that did not germinate in the first year.

PREVENTION OF INSECT PESTS

Tillage protects crops against some insects. Properly timed tillage before seeding, after harvest or during summer fallow will reduce populations of insect pests that spend part of their life cycle in soil or stubble. Elimination of weeds through tillage will starve insects in the spring or during fallow periods, prevent egg-laying or expose overwintering insects to predators and inclement weather.

Some insects are attracted to host plants during their egg-laying period in late summer and fall. Fallow fields that have volunteer or weedy growth should be worked to reduce egg production by insects such as grasshoppers, army cutworms and red-backed cutworms.

Pale western cutworm can be prevented from producing eggs by letting the soil form a crust from early August to mid-September. Do not cultivate, graze or disturb the soil in any way during this period. Pale western cutworms lay eggs in soft, dusty soil; if the soil has even a slight crust, the moths will not lay their eggs.

Soils that are crusted from late July until late September on summer fallow will prevent egg-laying by red-backed cutworm moths. If the provincial insect forecast indicates a significant risk of red-backed cutworm infestations, destroy weed growth in August because these moths prefer to lay their eggs in weedy summer fallow.

Newly-hatched insects may be starved by cultivation or with a herbicide treatment of new green growth, the food source for nymphs of grasshoppers, grubs of red turnip beetles and larvae of cutworms. Cutworm larvae can be starved before spring seeding by allowing volunteer growth to reach 3-5 cm before cultivation. Seed 10 -14 days after cultivation.

Control weeds throughout the period when grasshoppers hatch. Monitor summer fallow and crops regularly even though an initial hatch of insects has been controlled, because some grasshopper species may hatch during a period as long as six weeks.

DISEASE PREVENTION

Many disease problems can be prevented by simple and common sense management practices. Attention to the following practices will save labor and money if they prevent a disease from becoming established.

- Use disease-free seed. Many plant diseases are seed-borne. Do not introduce seed-borne diseases onto your land where they may persist and multiply on the crop residue. Such an example is virulent blackleg of canola. Seed-borne diseases can often be detected with a laboratory test, as for example, blackleg of canola and bacterial ring rot of potatoes. Test your seed for seed-borne diseases, especially when the seed is not from your farm.
- Grow disease resistant varieties whenever possible. Sometimes a resistant variety may not have as high a yield potential as a non-resistant variety, but the yield loss of a susceptible crop to a disease will more than cancel any yield advantage.
- Use field practices that prevent diseases from reproducing. Disc under or bury infected crop residue to encourage decay, keeping in mind the best soil conservation practices. Never allow a pest species to become firmly established.
- Practice effective weed control to remove volunteer crops and weeds that are alternate hosts of crop diseases. Diseases can persist from one year to the next on volunteer crops and weeds. Crop rotation is an effective pest deterrent because the rotation prohibits the carryover of diseases from one year to the next. As an example, diseases of cereals will not persist in a legume crop, if volunteer cereals and alternate hosts of cereal disease are controlled. Ineffective weed control can negate the effects of crop rotation.
- Scout your fields to identify new diseases and to monitor infection rates. If you note the start of a disease buildup, take immediate action to control the disease, salvage the crop by cutting the worst areas for forage or take other measures as required. If an overall disease buildup is noted, consider a rotation into a non-susceptible crop.
- Always practise good sanitation. Clean equipment before moving to a new field.
- Treat seed with fungicides or fungicide/insecticide combinations which offer low cost control for many diseases and some insect pests.

Many preventive practices are a minor nuisance to do but they can save major problems later. The recommendations mentioned here are only a sample. Think of things you can do on your farm. For example, you should purchase seed from areas that are free of the pests that are not present on your farm.

Quarantines and Inspections

To protect our agricultural industry, a number of regulations have been developed to govern the movement of plants and plant products. These regulations are intended to prevent the introduction of plant pests and restrict their spread.

A plant disease introduced to a new area is more likely to cause an epidemic and major yield losses, because crops grown in that area will not likely have any resistance to the disease.

The goal is to prevent the introduction of new diseases. Some diseases may be already present in Canada but are under an active quarantine; for example, the golden cyst nematode of potatoes in Vancouver Island and Newfoundland.

In response to the possible introduction of potentially devastating diseases and other pests, Agriculture Canada has developed a Plant Pest Emergency Manual. A current example of the use of this manual is the action being taken against the Asian gypsy moth infestations around Vancouver, British Columbia.

Embargoes

Embargoes exclude plant material on which a disease is likely to enter. Embargoes may operate only at certain times of the year. Table stock potatoes intended for domestic use may only be imported during the winter and early spring from certain regions of the United States, where a specific disease organism may be present; for example, Columbia root-knot nematode. This organism is not known to occur in Canada. Therefore seed potatoes for commercial use may not be imported from regions where the nematode is known to be present.

Inspection

At a port of entry (land, air or sea) or at the point of origin (for example, bulbs from Holland), plants and plant products are inspected to detect infested or infected material. If plants cannot be treated to kill contaminating pest organisms, the material will either be destroyed or denied permission to enter Canada and returned to its point of origin. Flower bulbs imported from Europe are subject to inspection. Flower bulbs from Holland may carry disease organisms such as the potato cyst nematode that could be of consequence to Canadian agriculture if the bulbs are grown near potato fields.

Controlled entry

Plants and plant products are allowed to enter Canada provided that disinfection or fumigation treatments will kill all stages of any pest or disease present in the consignment. For example, cereal seed of a known cultivar that has been multiplied (built-up) in another country during the fall and winter months must be treated with fungicide or fungicide combinations before it may enter Canada.

Post-entry and intermediate quarantine stations

These stations are used for the transfer of vegetatively propagated materials. Only small lots are permitted to enter. They are grown in an approved quarantine area and thoroughly inspected for diseases and other pests over a period of months or years before they can be offered for sale. This is done routinely with apple, cherry and grape bud wood that could carry diseases not present in Canadian orchards.

Public awareness and information dissemination

Often the general public unknowingly transports plant diseases, insects, weeds, weed seeds or vertebrate pests. It is important that the travelling public be aware of the danger posed by the introduction of new destructive pests into Canada.

Canada has a number of diseases that are under quarantine measures. These diseases are controlled by restricting imports that could be contaminated, such as potatoes. If the pest is present in the country, spread is prevented by restricting movement of the pest from that area; for example, dwarf bunt of wheat which occurs only in Ontario and British Columbia.

Quarantinable Diseases of Concern to Alberta

The North American Plant Protection Organization (NAPPO) regularly meets to identify pest problems of concern to Canada, the United States and Mexico. NAPPO regularly publishes a newsletter that discusses pest concerns, pesticide use and biological control procedures of interest to North American agriculture. NAPPO information can be obtained from the Plant Protection Division, Room 4109, K.W. Neatby Building, Agriculture Canada, Ottawa, Ontario, K1A 0C6
FAX: 613-995-6833.

Dwarf bunt of wheat (*Tilletia controversa*)

This disease of winter wheat is found in Ontario and the inter-mountain valleys of southern British Columbia. It causes yield and quality reductions. Grain from these areas does not enter either internal or export markets because of embargoes placed on this disease.

Flag smut of cereals (*Urocystis agropyri*)

This disease is not found in Canada. It can persist for many years in the soil. Importation of cereal seed into Canada is restricted by plant quarantine regulations.

Karnal bunt of wheat (*Neovossia indica*)

This disease does not occur in Canada. Strict regulations

exist governing importation of cereal grain from areas such as Mexico and India, where the fungus is present. The disease not only affects yield but is detrimental to the quality of grain for food, feed, seed or export intentions.

Columbia root knot nematode (*M. chitwoodi*)

This nematode primarily affects potatoes but it also attacks alfalfa, field peas and root vegetables. It is not found in Canada. The nematode is present in many areas of the United States and consequently importation of plants, plant parts or soil from those areas where the nematode disease is present is prohibited.

Golden cyst nematode (*Globodera rostochiensis*)

This nematode affects potatoes, tomatoes and related plants and is found only in eastern Newfoundland and on Vancouver Island, B.C. It may persist in a dormant state in the soil for 15 or more years.

Potato wart (*Synchytrium endobioticum*)

This disease is found only in Newfoundland and Labrador. Not only are the potatoes under quarantine restrictions but so are vehicles, machinery, construction equipment, sand, soil, sod, used bags, sacks and covers that could have had contact with contaminated potatoes.

Other quarantinable diseases

Other nematode pests and diseases of agricultural consequence are potato and soybean cyst nematodes, black stem rust of wheat, crown rust of oats, verticillium wilt of alfalfa, leaf spot of ginseng (*Colletotrichum panaciola*), tobacco blue mold (*Peronospora tabacina*), PVY_n virus of potato and white rot of onion (*Sclerotium cepivorum*).

The Federal Plant Quarantine Act, renamed the Plant Protection Act in 1990, prohibits importation as well as propagation, sale or movement of plants that serve as alternate hosts for crop diseases. This includes seeds of all species, hybrids and horticultural varieties of the *Berberis*, *Mahonia*, *Mahoberberis* and *Rhamnus* genus, which are susceptible to stem rust of cereals, and crown rust of oats.

Amendments to the renamed Plant Protection Act make enforcement of penalties more practical. Agriculture Canada officials may now issue tickets for minor infractions to those who wish to plead guilty. This will avoid courtroom proceedings that could be long and costly.

Agriculture Canada conducts campaigns, directed to the travelling public, not to bring back plant or animal material from out of country. One such instance is the brochure titled *Don't Bring it Back*. This pamphlet lists the prohibited, restricted and allowable plant or animal materials that may be brought into Canada. For example fresh root crops or citrus may be brought in from the United States but not potatoes. Citrus may be imported from any country into Canada.

If prohibited material needs to be imported into Canada such

as potatoes from Europe, then the importer has to meet the following requirements.

- The importer must be a researcher affiliated with a recognized research establishment.
- The importer must first obtain a permit from the Federal Permit Office.
- The shipment must be routed directly to the Plant Health Division at Ottawa for post entry quarantine.

Importation of apple, cherry, pear, plum, grape and other commercially propagation material into Canada that are not certified free of viruses or other designated quarantine diseases must be shipped to the Saanichton Plant Quarantine Station at Sidney, British Columbia. Here the material is indexed and treated to eliminate plant diseases, which may take three years or longer.

Importation of true seed of most plant species into Canada is generally unrestricted, except for specified agricultural seed crops. Importers must obtain an import permit before importing the seeds listed below:

- Wheat and triticale;
- Barley and rye;
- Oats, sorghum and millet from the following countries only: Afghanistan, India, Iraq, Lebanon, Mexico and Pakistan;
- Corn;
- Soybean;
- Fababean (*Vicia faba*);
- Peanut (*Arachis hypogaea*);
- All species of trees and shrubs;
- All species of aquatic plants;
- Ginseng.

Note: There are also import requirements in regard to the importation of alfalfa seeds (*Medicago sativa*) but a permit is not required.

Permits to import any of the above listed materials must be obtained before the shipment arrives in Canada.

Under the provincial Agricultural Pests Act, Alberta Regulation 406/86, the following diseases are declared to be pests through Alberta:

- Bacterial ring rot (*Corynebacterium sepedonicum*)
- Blackleg of canola (the virulent strain) (*Leptosphaeria maculans*)
- Columbia river root knot nematode (*Meloidogyne chitwoodi*)
- Dutch elm disease (*Ceratocystis ulmi*)
- Dwarf bunt (*Tilletia controversa*)
- Fireblight and the causal bacterium (*Erwinia amylovora*)
- Flag smut of cereals (*Urocystis agropyri*)
- Golden nematode (*Globodera rostochiensis*)
- Head smut of corn (*Spacelothecia reiliana*)
- Karnal bunt (*Tilletia indica*)
- Potato wart (*Synchytrium endobioticum*)

- Stem and bulb nematode (*Ditylenchus dipsaci*)
- White rot of onions (*Sclerotium cepivorum*)

The Agricultural Pests Act of Alberta includes many diseases and insects that are not covered in the Agriculture Canada, Plant Protection Act. The Province of Alberta Agricultural Pests Act also includes declared nuisances, birds and mammals that are the cause of problems in agricultural production such as pocket gophers and magpies.

Disease-free Certified Seed

Use seed that is sound and free from weed seeds, sclerotia, ergot bodies, smut or bunt balls, or infested or infected debris that could harbor disease spores. Contaminated seed is one of the major means to spread pests over long distances and introduce new pests onto the land. Seed can be sent for disease testing to Agriculture Canada, Seed Biology Laboratory, Seed Borne Disease Unit. Tests for the diseases listed in Table 1 are performed on a routine basis; other tests may be available on request.

Table 1. Routine tests performed for seed-borne diseases

Crop	Disease	Sample size (Numbers of seeds)
Cereals		
All	Surface borne smuts and bunt	1,000
	<i>Helminthosporium</i> spp.	1,000
Wheat	Glume blotch	1,000
	Fusarium	1,000
	Loose smut	1,000
Barley	Net blotch	1,000
	Leaf stripe	1,000
	Loose smut	1,000
	Barley stripe mosaic virus	5,000
Grasses		
Brome grass	Head smut	1,000
Pulse crops		
Peas	Ascochyta blight	1,000
Fababean	Ascochyta blight	1,000
	Chocolate spot	1,000
	Ascochyta blight	1,000
Lentils	Anthracnose	1,000
	Ascochyta blight	30,000*
Field bean	Anthracnose	1,000
	Ascochyta blight	1,000
Chick pea	Ascochyta blight	1,000
Oilseeds		
Soybean	Bacterial blight	5,000
	Phomopsis blight	1,000
Flax	Stem break	1,000
	Anthracnose	1,000
	Pasmo	1,000
	Alternaria	1,000
Forage legumes		
Alfalfa	Verticillium wilt	10,000
	Bacterial wilt	10,000

*For certified or commercial beans submit 2 kg of seed; for foundation seed, submit 4 kg.

Include all pertinent information with the sample including, grower's name, where grown, CSGA grower number and crop certificate (when applicable), lot or other identifying numbers, etc.

Samples should be submitted to:

Seed-Borne Disease Unit,
Laboratory Services Division, Bldg. #22
Agriculture Canada
Central Experimental Farm
Ottawa, Ontario K1A 0C6

A private plant disease diagnostic clinic located in Brooks, Alberta now offers many of the plant disease diagnostic services formerly offered by only the federal and provincial governments.

Sanitation

Sanitation includes all activities used to reduce or eliminate the presence of pests in the field and storage facilities as well as prevent their spread to healthy plants and plant products.

Burial of disease-infected crop residue at least 5 cm deep by discing or deep cultivation prevents fungal spores produced on the surface of crop residue from being released into the air to infect growing plants. Tillage promotes the decay of crop residue and root systems. This shortens the time disease organisms can survive on host material.

Disease spores may be present in soil, plant residue, hay, manure or feed materials. Movement of these can result in both long and short distance spread of disease. Alfalfa hay infected with verticillium wilt can be moved province-wide through hay sales. Take-all of wheat can be moved from an infested field to a clean field by soil-contaminated harvest equipment.

A complete and thorough harvest of all forage in a field reduces the re-infestation of forage fields; the new growth will be relatively free of disease.

The presence of some diseases requires a thorough disinfection of all handling equipment and storage facilities. This prevents the contamination of uninfested seed or new seed brought on to the premises.

If *Septoria* glume blotch or tan spot occurs in dryland wheat, then the only disease control alternatives are turning under the straw or a crop rotation. Turning under the straw in continuous wheat reduces the abundance of the fungus-infested straw on the soil surface. The lowered inoculum level that results from cultivation may delay the buildup of disease by one to three weeks. If this disease delay occurs in mid to late July at the critical post-flowering stage, the yield increase due to cultivation could range from 10 to 25 per cent. Similar yield increases could occur in barley crops if cultivation is used to delay scald and net blotch.

Pesticides

Pests are living organisms that cause damage and loss of crop

yield or quality. Insects, fungi, bacteria, viruses, weeds and rodents can all be pests. Pesticides are categorized by the kind of pest that is controlled:

- Fungicides kill or control fungi.
- Herbicides kill or control weeds.
- Insecticides kill or control insects.
- Rodenticides kill rodents.

Federal and provincial regulations govern the licensing, sale and proper use of all pesticides. The federal act governing the use of pesticides is the Pest Control Products Act, administered by Agriculture Canada. This act governs the registration, labelling and classification of all pesticide products. Pesticide products range from restricted chemicals that can be administered only by appropriate licensed operators to products that may be used by individuals for lawn weeds and insect repellents.

Provincial legislation governing the use of pesticides, the Alberta Environmental Enhancement Act is administered by Alberta Environmental Protection, Pesticide Management Branch. Under this act, pesticides are grouped into four categories and licensed in up to 12 specific operator classes. Alberta Environment administers study courses and examinations so that pesticide operators may qualify to use one or more classes of pesticides.

Minimum Tillage and Zero Tillage

Minimum tillage maximizes disease potential by allowing diseased crop residue to remain on the soil surface. However, rusts and smuts of wheat are not affected by zero or minimum tillage because rust spores are moved in by winds from the United States and smuts are borne in or on the seed.

If minimum tillage coupled with continuous cropping is here to stay, disease control strategies must change. Resistance to leaf diseases must become a plant breeding priority, but when genetic resistance is non-existent we might have to resort to fungicidal control, particularly on irrigated land.

The consequences of minimum tillage include the following:

- loss of a cultural disease control,
- an increase in plant diseases,
- possible use of foliar fungicides,
- a change in the weed species that are prevalent,
- breeding crops (cereals) resistant to leaf diseases and root rots,
- research on fungicide efficacy (application rates, timing and costs),
- development of disease forecast systems.

Minimum or zero tillage conserves soil moisture, reduces soil erosion and lowers labor and fuel costs. Unfortunately, it may increase certain weed and disease problems or cause a shift in the pests that are present in the field.

Crop Rotation

Crop rotation is an extremely important tool for reducing farm pest problems. Annual weeds can be controlled through the use of forage crops, while perennial weeds are controlled when annual crops are planted. Insects and residue-borne fungal and bacterial diseases are controlled by the lag time between susceptible crops. As well, a good crop rotation improves the condition of the soil.

There are two types of rotation. The so-called short rotations may include a cereal crop or two, an oilseed and perhaps summer fallow. The short-term rotation allows the producer to select crops in response to market conditions and to select crops that are resistant to some pests. A short rotation also allows the growing of crops responsive to herbicide applications that control a variety of weeds. Short rotations do little or nothing to enhance the soil unless a green manure crop is included as part of the fallow.

Longer-term rotations can include perennial crops such as forage legumes and grasses, which not only break weed and pest cycles but also enhance the soil. Longer-term rotations are more difficult to change in response to the market and require careful planning and preferably a mixed farm operation.

Rotational control can eliminate or reduce disease levels in a field. By growing crops that cannot be infected, disease organisms will die out. The number of years between successive crops depends on a disease organism's ability to survive in the absence of its host crop. Crop rotation is particularly effective against short-lived soil and residue-borne diseases.

Short-lived diseases

The effectiveness of crop rotation as well as the suggested time interval between crops will vary with the disease. Effective control through crop rotation is only possible with diseases that are specific to their hosts (for example, flax and sunflower rusts) or diseases that survive only on living plant tissue or its residue (for example, scald of barley). For these diseases, fairly short rotations are usually effective. However, infectious spores are often produced for years on crop residue and may also blow in from adjacent fields. Crop rotations are not effective unless accompanied by other management practices such as plowing under or deep tillage of the crop residue, controlling volunteer seedlings and weeds, and not growing susceptible crops adjacent to the previous year's stubble.

Long-lived diseases

Crop rotation becomes less effective when disease-causing organisms are not host specific, produce long-lived spores or can survive for many years in the soil. Examples of these include verticillium wilt of alfalfa, sclerotinia white mold of canola, and root rots of barley, canola and wheat. For these diseases, long crop rotations are useful in reducing, but not eliminating, the populations of the disease-causing organisms. Susceptible crops can only be grown

once every three, four or five years, to reduce disease levels in heavily infested fields. Crops must be watched closely for symptoms of disease. When they are identified, their significance should be evaluated for the following year's cropping sequence. Cropping sequence in which crops are planted in a particular field is an important part of disease management.

Table 2. Disease considerations in crop rotations

Crop	Disease risk	Should not be grown after	Reason
Barley, wheat	1	Barley, wheat	Leaf diseases, root rot
	2	Corn	Scab (head blight)
	3	Fall rye	Ergot
Flax	1	Sugar beets, peas, lentils, summer fallow	Rhizoctonia
	1	Flax	Rhizoctonia (rust where rust susceptible varieties are grown)
Fall rye	1	Rye	Ergot
	3	Wheat, barley	Ergot
Canola and mustard	1	Canola, mustard rapeseed	Sclerotinia, rhizoctonia, Blackleg
	1	Sunflowers,	Sclerotinia
	2	Lentils	Sclerotinia
Sunflowers	1	Sunflowers	Sclerotinia, Verticillium, downy mildew, rust
	1	Canola, rapeseed and mustard	Sclerotinia
	2	Lentils	Sclerotinia
Field peas Fababeans	1	Field peas,	Ascochyta, bacterial blight
	2	Sugar beets, alfalfa, flax,	Rhizoctonia Pythium, Fusarium
Beans, lentils	2	Sunflowers, lentils, canola, rapeseed, beans fababeans, mustard	Sclerotinia
Sugar beets	1	Flax, peas	Rhizoctonia
	3	Potatoes	Rhizoctonia, Fusarium tuber rots

Rating: 1 - High risk of severe disease development.
2 - Moderate risk of severe disease development.
3 - Low risk of severe disease development.

Canola in the Peace region should not follow fescue because the high organic content and moisture holding capacity of the sod increases the amount of root rot in the canola. The high organic content of the sod will tie-up available soil nitrogen needed by soil micro-organisms for

the sod breakdown. Fertilizer levels must be adjusted to compensate for this temporary nitrogen deficiency.

Factors that must also be considered when planning crop rotations in a field are:

- weed history,
- possible herbicide residues,
- soil fertility,
- volunteer growth from the previous crop.

Volunteer growth may cause serious competition and seed separation problems as well as supporting the growth of plant diseases.

Crop rotation assists in control of insects by continually changing their food supply and living conditions. A crop rotation that alternates between susceptible and immune crops will discourage the buildup of pest populations. For example, wireworms can be controlled almost completely if cereals are rotated with a non-grass crop. As cereal and broad-leaved crops tend to have different insect pests, rotation will discourage their buildup. Switching to a different cereal crop can eliminate certain host-specific pests. Barley thrips and wheat midge, for instance, infest barley and wheat (respectively) more severely than other cereals.

Crop rotation is sometimes enhanced by growing different crops in mixed populations. Examples include underseeding cereal with clover, a grass-legume hay combination, mixed grains, or a silage mix of peas and oats. Insect populations in such plantings are normally more complex and thus more stable, providing a better balance between pests and their natural control agents.

The use of fallow in a rotation is controversial. Summer fallow contributes to soil erosion and is appropriate only for areas where moisture is very limited. Even then, alternative practices for weed control are encouraged. It is preferable to combat weeds by using crop rotation and crop competition.

Despite the problems associated with fallow, it plays an important role in breaking the life cycle of diseases and insects. The benefits of fallow in controlling perennial weeds are well known. However, fallow has been practised so long in southern Alberta that many of our current pests are those that have adapted to fallow (for example annual weeds and cutworms). Breaking the normal fallow-crop rotation may be beneficial.

Crops Commonly Used For Rotations

Spring-seeded annual crops

The first flush of weeds can be destroyed by tillage before

spring seeding. Weeds that germinate later in the season such as green foxtail and shepherd's-purse, may increase if a field is repeatedly seeded in the spring. Spring-seeded annual forages are an alternative to perennial forages,

especially on weedy land. Annual forages should be cut before weeds flower, to prevent formation of viable seeds.

Legumes

Leguminous cover crops prevent erosion, fix nitrogen in the soil, reduce the need for nitrogen fertilizer, loosen the subsoil, improve soil structure and organic matter, smother weeds, and starve insects and diseases of non-legume crops.

Underseeding or companion seeding

The principle of underseeding or companion seeding is to crowd weeds out. For example, planting clover beneath cereals provides strong competition for weeds. After cereal harvest, the clover can be used as forage or green manure. Companion seeding means growing several varieties at the same time, such as a grass and a legume, mixed grains, or a silage mix of peas and oats. These plantings ensure a variety of habitat for beneficial insects and use light and soil nutrients to the detriment of weeds.

Row crops

Summer annuals, like wild oats, are usually a problem when spring grains are grown continuously or in rotation with summer fallow. Problems with summer annuals can be reduced by using row crops such as sugar beets, potatoes, field corn, peas and beans. When planning a rotation with grain crops, select a row crop compatible with the climatic conditions in your area. As a good rotation for weed control, include both summer row crops and winter or early spring grain crops such as fall rye, winter wheat, or early barley. Row crops that are unrelated to common oilseeds and grains are helpful in preventing the buildup of many common insects and diseases.

Perennial forage crops

Perennial forage crops or pastures seeded with introduced grasses effectively reduce populations of annual weeds and some insects. Annual weeds must be controlled during the seedling stage of the crop. Once perennial forages are established, mowing and competition will suppress weeds. Eventually, vigorous competition will eliminate annual weeds almost completely.

The forage stand must be left for a number of years to allow buried weed seeds to rot. Some weed seeds will stay dormant and germinate when the forage stand is broken. The first year after breaking a forage stand is critical, because the field will be re-infested if prompt control measures are not taken. With careful management, none of the

weeds that grow in the year after breaking should ever produce seed. This land can remain clean for many years. Leaving parts of a field in forage and unharvested provides a lasting habitat for beneficial insects and birds. Some perennial grasses, especially crested wheatgrass, compete better than perennial legumes. The competitive ability of crested wheatgrass is compared with several perennial weeds in Table 3.

Table 3. Effect of crested wheatgrass on density of perennial weeds

	Number of weeds per square yard						Per cent reduction
	Before grass was sown	Year after grass was sown					
	1	2	3	4	5		
Perennial sow							
thistle	112	61	3	1	0	0	100
Toadflax	187	108	27	2	0	0	100
Canada thistle	27	27	17	5	2	0	100
Field bindweed	93	70	63	54	53	48	49

From Paulyuchenko and Kirk.

Fall-seeded crops

Fall rye and winter wheat are effective in weed control programs where it is practical to grow them. Fall rye will grow much further north than winter wheat, but even rye can be killed by snow mold fungi in the Peace region when snow cover remains late into April. These crops give early season competition to weed seedlings and their early harvest date enables a partial summer fallow for the balance of the year. This two-pronged approach provides for control of both annual and perennial weeds.

Winter annual weeds are a problem in fall-seeded crops. These weeds emerge with the crop and form overwinter rosettes. In the spring, the winter annual weeds flower and produce seed long before the crop can be harvested. Some winter annuals can be controlled in the crop by using 2,4-D. Others must be controlled by rotations.

In the year of establishment of a perennial crop, weed control can be as simple as mowing or cutting before weeds go to seed. Weeds contribute to the feed value of hay; after they are cut the crop will gain a competitive advantage.

Perennial crops should be left down for three to five years. This allows time for the crop to compete against weeds and deplete the number of buried weed seeds. Weed control must immediately follow breaking of sod because the dormancy of many seeds will be broken and they will germinate as soon as the soil is plowed.

Greenfeed

Greenfeed crops can be used when weed infestations are very heavy and profitable cereal production is questionable. Oats are generally used because they make better hay or silage than other cereals. The greenfeed crop should be cut or thoroughly grazed before the weeds bloom. By cutting at this time, the greenfeed will be free of weed seeds and a population of weeds will have been harmlessly grown out. Weeds must be

watched carefully if the weather is good for regrowth. A second cutting or tillage may be necessary to prevent weeds from producing seed because seed production can take place without much additional top growth. Alternatively, the forage can be turned under for both green manure and weed control.

In the wetter parts of Alberta, a combined greenfeed and summer fallow operation may be effective. Seed greenfeed early in the spring. Then till after the infested crop has been used for pasture, hay or silage. The strategy is to begin to summer fallow before the seed-set of annuals and when perennials have depleted their root stores of nutrients.

Variety selection

Enhance the benefits of crop rotation by selecting varieties that will discourage local pests. Pick a variety suited to the growing conditions, and thus vigorous enough to withstand some pest damage, or select a variety that matures earlier (or later, in some cases) than the pest does, and so avoids damage.

Some varieties have been bred to resist insect attack. For instance, solid-stemmed wheat varieties are resistant to wheat stem sawfly and most of the alfalfa grown in the western United States is resistant to spotted alfalfa aphid.

SEED SELECTION AND TREATMENT

There is no substitute for good seed. The selection of regionally adapted cultivars is of utmost importance. Select varieties that suit your specific growing requirements. Many of the newer varieties have agronomic characteristics that exceed some of the older varieties. Use a proper crop rotation and ensure that succeeding crops will not serve as a host for future disease problems.

Use Resistant Varieties

The use of resistant varieties of crops is the most efficient and cost effective means of disease control. There is no additional cost of operation, no hazard to the farmer or the environment and little or no disease carryover in the crop residues. Resistance to specific disease can be through

- early maturity that permits plants to escape the infection period
- endurance and vigorous growth that permits the plants to mature despite the presence of disease and
- natural resistance to infection from structural or physiological characteristics that prevent infection.

Seed Treatments for Control of Disease

Mechanical treatments

Mechanical treatments remove infectious materials that are mixed with seed. Seed processing is an integral part of the technology that transfers the genetic engineering of the plant breeder into improved seed. Contaminants such as inert material and off-sized seed influence how well seed flows through the seed drill and plants. Insect and disease infestations contribute to storage problems. As well, other contaminants such as seed from weeds and other crops and varieties affect production of crops if they are not removed.

Research on large, medium and small seed has consistently shown that large seeds are the most productive. Small seed has higher levels of disease (for example, smut) as well as reduced vigor. Yield tends to increase with the use of large seed.

Table 10. Effect of seed size on yield of soft white winter wheat in Oregon

Seed Size	Bushels/acre			
	Hyslop	McDermid	Stephens	Yamhill
Large	77	80	76	78
Ungraded	73	78	74	75

Physical treatments

Physical treatments are used primarily to kill pathogens deep in the seed. The main methods are a hot water treat-

ment and a water soak treatment. The physical treatments do not protect seeds against soil-borne organisms.

The hot water treatment requires adequate steam or hot water, accurate thermometers, water tanks or vats, and drying facilities. This treatment method has been used primarily to disinfect small lots or batches of crops with small seed that require low seeding rates.

All water soak treatments require the seeds to be soaked in water at least two hours and subsequently kept under anaerobic or near anaerobic conditions for one or more days.

These methods have not been used extensively because it is difficult to control the temperature and duration of treatment.

Chemical treatments

Chemicals are the most common seed treatment. Many excellent chemicals are available. In conjunction with mechanical treatments, chemicals are the most effective control of seed-related diseases. Follow label instructions and use the proper safety measures when handling any of these products.

Seed Storage

Deterioration of stored seeds by fungi is controlled primarily by drying seeds to a safe moisture content before storage in a dry place. Seeds that contain too much moisture are susceptible to invasion by storage disease fungi which in turn may spread throughout the lot. Pockets of moist seeds can occur in low moisture content seeds due to roof leaks, insect activity and moisture translocation. Heating is likely to be the effect of mold invasion of the seed and not an indication of seed deterioration. Fumigation to control insects usually has no detectable effect on storage fungi.

Insects

Stored seed is attacked primarily by those insects that destroy stored grain and grain products. Weevils puncture the seed coat and destroy the endosperm while other stored-product insects attack the embryo. In either case the germination potential of seed is greatly reduced or destroyed.

Fumigation of seed and seed handling equipment can help to control insects.

Rodents

Rodents destroy thousands of pounds of seed every year. Much of the loss comes from the seed they scatter and foul, not what they eat. The best way to control rodents is to keep

them out of seed storage areas. Cleanliness inside and outside storage areas helps keep rodents away. Rodents can be eliminated with traps, baits or fumigation.

Seed Testing Certificates

A valuable guide for purchasing seed is a seed testing certificate. The document is available with every lot of seed that has been graded in Canada. Seed testing certificates should be examined before making a final decision about which seed lot to purchase.

The seed testing certificate contains the following information:

- seed testing certificate number
- crop certificate number
- seed sealing number
- crop kind
- grade
- amount and name of prohibited primary and secondary noxious weeds, other weeds and seeds of other crops
- percentage pure seed, other crops, weed seed and inert matter
- germination percentage
- place and date of analysis and name of the seed analyst.

SEEDING AND FERTILIZATION

Strong, healthy crops have a competitive advantage over weeds, but crop species vary in their ability to compete. Perennial crops, after the year of establishment, provide competition for weeds, particularly annual weeds. Fall rye and winter wheat compete well because they resume growth in early spring before weeds have emerged. Cereals are generally the best annual crop competitors. Barley is more competitive than spring wheat. Canola is the most competitive oilseed with flax being the poorest. Crops such as lentils, peas and beans are generally poor competitors, owing to low plant populations and slow initial growth. Varieties also differ in competitiveness. For example, the semi-leafless pea variety Tipu is less competitive than Century in areas infested with wild mustard.

Crops have some defense mechanisms to deter pests; many can withstand a certain amount of pest damage when they are well nourished and healthy. Crops are susceptible to disease when they are stressed or poorly nourished. A well-prepared seedbed in good fertile soil will enable crops to resist many pests. Place fertilizer where it benefits the crop more than the weeds. Shallow seeding and packing will establish a vigorous stand. Avoid seeding too early; cold soils will retard seedling growth and make the crop susceptible to disease. Heavy seeding rates to establish early competition for weeds will also compensate for some plants being lost to pests. A vigorous crop can carry more insect damage without yield reduction, so fertility is doubly important if pest problems are anticipated.

The seedling is the most vulnerable stage of growth, and because many insects emerge from hibernation just when seedlings emerge, a variety of special seeding practices have been developed.

Rates

Seeding at rates 25 per cent greater than normal will help crops compete with weeds by providing a lush crop canopy. Heavier seeding rates of cereals allow a margin for crop damage from post-seeding tillage. However, under extremely dry conditions, heavier seeding rates cause the crop to compete with itself for moisture. For this reason, heavy seeding should not be practised in very dry areas.

Heavy seeding rates can compensate for a certain degree of seedling mortality by insects, especially in wheat when wireworm damage is possible. If the infestation is patchy, doubling the seeding rate in susceptible areas is a possible control option. A thorough field scouting program is required.

Table 11. Average seeding rates in Alberta

Region	Barley bu/ac	Wheat bu/ac	Canola bu/ac
1	1.25	1.25	2-5
2	1.25	1.25	2-5
3	1.75	1.25	5-6
4	1.75	1.25	5-6
5	1.75	1.75	5-6
6	1.75	1.75	5-8

Depth

Planting shallow into moisture will encourage rapid crop emergence. This will prevent weeds from emerging before the crop. Weeds that emerge before the crop cause significantly greater yield losses than those that emerge after.

Table 12. Some recommended seeding depths

Crop	cm
Cereal, lentils	4 to 5
Canola, flax	1.3 to 4
Forage grasses, legumes	1.3 to 2
Peas, beans (large seed)	6 to 10

Timing

Crops seeded shallow into warm (5°C or warmer), moist soils germinate and emerge quickly and evenly. Tillage at or before seeding will destroy weed seedlings and give the crop a head start.

By seeding when the soil is both warm and moist, the crop gets a head start and establishes itself before the pest does. Moisture is especially important. For instance, wireworms can destroy up to 95 per cent of a crop sown in dry soil compared with up to 10 per cent in moist soil.

Early seeding is sometimes used so that crops are advanced when grasshoppers, cutworms and wireworms hatch. Another advantage of early seeding of a fast growing variety is that the crop matures before the development of late season pests and weeds such as aphids and green foxtail.

Use delayed seeding to control weeds such as wild oats, which germinate under cool soil conditions. Early spring tillage encourages weed germination. Till and plant after weed seedlings emerge. Late-planted crops usually yield less and are vulnerable to frost in the fall. Choose an early maturing crop or variety to minimize yield losses caused by frost. Do not use delayed seeding when moisture is extremely limited.

Delayed seeding may also be used to time seedling emergence to occur after a destructive insect stage has passed. For instance, if a heavy cutworm infestation is expected, seeding can be delayed until the cutworm larvae have stopped feeding.

It is also possible to reduce sawfly damage by delaying seeding, because the stems of young plants are not developed enough to be attractive to egg-laying female sawflies.

Certain risks are associated with late seeding. If spring weather is cold and wet, pests will be delayed right along with the crop. Late seeding results in lower yields, and early maturing varieties usually yield less. This loss of yield must be balanced with the expected cost of control and the reliability of predicting insect damage.

Disease development is affected by the date of planting, soil temperature at planting and depth of planting. If Tobin canola is planted too early or too deep, the incidence and severity of seedling blight increases markedly. Seed treatments will be of little help in reducing seedling disease if the soil is below 5°C and dry.

Seedbed Preparation

A firm, well-packed seedbed maximizes soil moisture contact with the seed. This promotes uniform seeding and seedling emergence. Before seeding, the seedbed should be firm enough so that heels sink no deeper than the thickness of the sole on a normal work boot. This will also provide better depth control with the seed drill.

Fertility

Nitrogen (N), phosphorus (P) and potassium (K) are the major macro-nutrients essential to crop production. N and P limit crop yields in most regions and a few areas are low in K. Soil tests identify the levels of all soil nutrients.

Sulphur (S) is an essential element. Where sulphur levels are deficient, yield losses will result in crops such as canola without the addition of sulphur. Sulphur deficiency occurs in patches, most often on Gray Wooded soils. Canola on sulphur-deficient soil is stunted, with yellowish cupped leaves, red discolorations and poorly filled or empty seed pods. Soil tests identify sulphur levels and deficiencies can be corrected by applying fertilizers that contain sulphur.

Copper (Cu) deficiency has been identified on sandy soils and soils with a high organic matter content. Copper deficiency contributes to a condition known as melanosis in wheat, where the grains fail to form. Wheat varieties such as Park, Biggar and Roblin appear to be very susceptible to this condition. On high organic soils in west-central Alberta, Cu deficiency is associated with low yields of barley. Research is underway to find economical ways of adding available Cu to soils to correct these conditions.

Other micro-nutrients that have occasionally been identified as deficient are manganese (gray speck disease of oats), boron (in canola and alfalfa), zinc (in beans), molybdenum (in alfalfa) and iron (on alkali soils). If any of these nutrients are limiting, they become the weak link in the production chain and limit yield even though other nutrients may be present in ample quantities.

Vigor of crop plants increases with the use of fertilizers.

Phosphorus promotes root development and allows crops to compete more effectively with most weeds. Weeds such as green foxtail respond to nitrogen fertilizer applications thus reducing the crop's competitive advantage. Generally, under wet and cool conditions, the use of fertilizer is an effective tool in promoting crop growth. Broadcasting nitrogen stimulates weed growth because the fertilizer is readily available to the weeds, as well as the crop. Banding fertilizer is more advantageous to the crop.

Improper fertilization practices may cause crop problems. Placing too much phosphorus or nitrogen fertilizer with the seed will damage tender seedlings by a simple salt (burning) effect. This reduces the plant stand and yield. Crops under stress from too little or too much fertilizer become more susceptible to disease. Good plant nutrition is one of the best ways to avoid disease problems.

Consider the choice of fertilizer. For example, the number of sugar beet plants affected by seedling blight (*Rhizoctonia solani*) can double when ammonium-type nitrogen is used as opposed to nitrate-type nitrogen.

Soil fertility affects the vigor of both crops and weeds. Many weeds use fertilizers as effectively as or better than crop plants. If most of the weeds are suppressed or killed by tillage or herbicides, the extra vigor given to the crop by fertilizers will make the crop plants better able to resist disease.

High nutrient levels in the soil can lead to crop lodging because most crop varieties were developed to cope with lower levels of fertilizer inputs. New on the scene are growth regulators that can dwarf naturally tall-growing crops, reducing their tendency to lodge.

Lime

Certain diseases tend to be associated with alkaline and acid soils. For example, alkaline soils favor take-all of wheat, while acidic soils favor clubroot in canola.

Alfalfa does best in well-drained soils with a pH range from 6.5 to 8 (neutral to alkali soils). At pHs of 6 and lower, the reduced vigor, poor nitrogen fixation, poor winter survival and susceptibility of alfalfa to disease make it uneconomical to raise this crop. In soils of pH 5 to 6, grow alsike or red clover; both are able to fix nitrogen at low pH levels. In northern Alberta, alfalfa is grown on soils around pH 6, but great care is taken with inoculation of the nitrogen-fixing *Rhizobium meliloti* bacteria, which do not normally thrive well in soils of this pH. In neutral soils, the alfalfa nitrogen-fixing bacteria do well and can persist for many years in the absence of alfalfa plants.

If land is on the acidic side (below pH 6), is it economical to lime soil? There is no shortage of limestone in Alberta since the entire eastern slope of the Rockies is made from this material. Crushing and transporting the rock are costly. Most field crops, including cereals and oilseeds, will do well at pH 5.5 or higher but anything less will cause significant yield reductions as a result of acid soil conditions. To move a soil pH from 5 to 6 would require about 2 tons of limestone (or marl) per acre at

a cost of \$25 to \$30 per ton. The effect of lime, depending on the nature of the soil, can last 10 to 15 years. Would an input cost of \$50 to \$60 per acre be justified in increased crop yields?

Growers who are content with an average of 50 bushels per acre of barley on acidic soil with a pH of around 5 do not lime. However, to expect a yield of 100 bushels per acre with intensive crop management on acidic land, liming is an important consideration.

Crop Placement

Plant susceptible crops far from infested stubble. Surround susceptible crops with different crops. Isolate susceptible crops with summer fallow strips. However, isolation of a crop

is often ineffective because many pests can fly or are wind-borne. For example, bertha armyworm and cabbage root flies can readily find a canola crop. However, the isolation strips work well to prevent extensive sawfly damage in wheat.

Crop Selection

The crop chosen depends on the weeds and other pests present. The weed species in a field will be dependent on past cropping systems. Choose a crop based on the worst weed problem or the one suspected to be causing the most yield loss. For example, in a field infested with both Canada thistle and common groundsel, select a crop that permits Canada thistle control because it is by far the worst of the two. For more details refer to the section on crop rotations.

PHYSICAL CONTROL OF PESTS

Physical control refers to mechanical or hand controls where the pest is actually attacked and destroyed. Physical controls are used mostly in weed control. Tillage, fire, removal by hand, grazing and mowing are all used to destroy weeds and prevent reproduction. Some insects may also be destroyed by tillage, which destroys their eggs or overwinter stages of growth.

As stated previously, weeds are not controlled through a single operation. Practices such as seedbed preparation, post-seeding tillage, post-harvest tillage and summer fallow are effective in combination against weed seedlings and perennial weeds. The choices will vary with the region, crop, degree of infestation, soil condition and availability of equipment. Soil factors influence the selection of machinery. For example, stones may prevent mowing and moisture conservation may prevent the use of repeated tillage. Consider all factors before you develop an integrated control program.

Harvest Practices

Strip harvesting

Strip harvesting leaves an unharvested strip of crop in the field, which preserves natural enemies of pests, prevents mass migration of pests and improves snow management. The harvest of a whole field of an infested crop may force insects such as beet webworm, pea aphid, cutworms and grasshoppers to migrate to another field. If the crop harbors beneficial insects (as it almost certainly will if it is infested), the harvest often destroys them, their habitat and their insect food source. The next parasite generation may even be removed from the field with the harvested crop. Thus, the pest often moves to a new crop free of its natural enemies. Strip harvesting helps maintain a stable ecosystem.

Successful strip harvesting is practised in alfalfa pest management. Alfalfa provides an ideal habitat for a variety of insects, ranging from pests (alfalfa weevil, lygus bugs, pea aphid and alfalfa plant bug) to beneficial insects (damselfly bugs, lacewings, ladybird beetles, pirate bugs, wasps, spiders and leafcutter bees). Harvesting alfalfa causes winged pea aphids to migrate and settle on other crops, while many of the beneficial insects are destroyed. There are, for example, tiny wasps that sting and deposit eggs in aphids. These parasitized aphids will be destroyed with the harvested crop, but winged healthy aphids will migrate to new areas, free of an entire generation of wasps.

To strip harvest alfalfa, cut alternate rows. When the rows that were cut have undergone some re-growth, cut the remaining rows. Alternatively, simply leave some strips or patches unharvested. Strip harvesting also provides a deeper snow cover. This can reduce winter kill during severe winters and enhances spring soil moisture conditions.

Early swathing

Early swathing can sometimes save a crop. By the time wheat that is infested with sawfly reaches maturity, the stems may have collapsed, making harvest impossible. Badly infested fields may be saved from pests such as wheat stem sawfly (or weeds) by an early harvest or by the production of hay or silage.

Unless diseases or pests are suspected, or fast drying is required, grains should be straight combined whenever possible. Straight combining permits a taller stubble and improves snow management.

The time of harvest may affect disease development and yield. *Alternaria* black spot of canola and mustard attacks pods late in the season. Early swathing of badly infested crops may reduce losses caused by shattering. Lay swaths so that air can circulate beneath the grain to encourage drying. If canola remains moist, *sclerotinia* white mold can continue to spread in the swath.

The grains of cereal crops that have lain overwinter in the swath, particularly under a snow cover, may become infected with fungi that can produce mycotoxins under certain conditions. Mycotoxins are poisonous chemicals that occur naturally as by-products of fungal species such as *Cephaelosporium*, *Fusarium* and *Aspergillus*. *Fusarium* can produce vomitoxin, which may be present in hay and grain and results in production losses in animals and illness in humans.

A group of mycotoxins, the ochratoxins, may be carcinogenic and may be found in trace amounts in grains that heat during storage on prairie farms. These mycotoxins are sometimes present in the meat of poultry and hogs that have consumed contaminated feed.

Mowing

Repeated mowing controls perennial weeds by depleting root reserves. It will also prevent seed production of annual and biennial weeds. Root reserves in perennial weeds are lowest when plants are in bud. If only one mowing is planned, it should be at this stage. Mowing is not effective for prostrate weeds such as field bindweed.

Mowing is often harmful to beneficial enemies of farm insect pests. Farmers need to know the life cycle and habitat needs of the beneficial species, so they can adjust mowing practices. One obvious example is the provision of habitat for birds. Birds consume huge quantities of insects and many of them nest in grass. Early mowing is one cause of nestling mortality. Wherever possible, the farmer should avoid mowing or heavy grazing until mid to late July.

Hand pulling

Although small patches of perennial weeds can be pulled up repeatedly, hand pulling is most effective for annual and

biennial weeds. Pulling of annual weeds prevents seed production. If weeds are in flower, bag and burn them to prevent seed spread. Hand pulling is most feasible when you are trying to prevent the establishment of new species. Hand rouging is a routine practice on pedigreed seed farms and is practical even on large areas if the infestation is light.

Tillage

Tillage was one of the first methods of weed control. It is fundamental to integrated weed control. Annual weeds, biennial weeds without extensive tap roots, and perennial seedlings are readily destroyed by tillage. The younger the weed, the easier it is to control. Tillage effectiveness relates directly to the amount of soil disturbance. The greater the disturbance, the greater the effect of tillage is on weed control.

The choice of implement depends on residue cover, soil type, soil moisture, growing conditions and weed growth. Blade implements, such as the Noble or Victory blade cultivators, conserve trash but are not very effective under cool wet conditions. Implements that bury plant residues are effective in wet conditions but increase erosion potential. Reduced tillage is desirable in the Brown and Dark Brown soil zones, particularly on sandier soil and following dry years that produce little residue cover. Field cultivators and rod weeders are a good compromise.

Table 13. Percentage of straw reduction by selected tillage operations

Soil moisture conditions	Implement	Surface residue reduction
Moist	Plow	100
	Tandem-disc	50-60
	Rod weeder	5-10
	Field cultivator	20-30
	Chisel plow	15-20*
Dry	Blade cultivator	5-10*

*less residue loss with low crown sweeps.

Summer fallow

Summer fallow is used to control weeds, conserve moisture and nutrients, and retain crop residue to protect against soil erosion. Summer fallow is most effective against perennial weeds. However, it is also helps deplete the supply of weed seeds in the soil because tillage promotes germination of weed seeds.

As flushes of weeds appear, they are controlled by tillage or with herbicides. Use herbicides when tillage is not effective or where soils are susceptible to erosion. Summer fallow contributes to erosion, salinity and organic matter loss and therefore should be used with care. Field cultivators with wide sweeps sever roots of annual and perennial weeds. After the soil has been loosened, a rod weeder will penetrate and provide good annual weed control with minimum moisture loss. Blade cultivators can be used in dry areas where minimal soil disturbance is desirable. Till during hot, dry but calm weather.

One year of summer fallow will reduce weed problems, but

not eliminate them. Dormant weed seeds will remain to germinate and emerge in subsequent years.

Pre-seeding tillage

Shallow tillage (less than 7.5 cm) in early spring encourages germination of most weed seeds. A second shallow tillage will destroy the seedlings and prepare a seedbed. Use a disc-type implement if crop residue is heavy. A rod weeder or cultivator will work when less residue is present. This practice is most effective for weeds that germinate in cool soils such as wild oats, mustards and hemp nettle.

Post-seeding tillage

This practice will control weeds that emerge with or shortly after cereal crops, sunflowers and potatoes. In some instances post-seeding tillage can cause severe crop injury and should be done with caution. For example, inter-row cultivation of corn and vegetables is a less injurious form of post-seeding tillage than a blanket cultivation. However, rod weeding of cereal crop to destroy early emergent weeds when the crop sprouts are still below the depth of the rod weeder is a relatively safe practice. Well-established cereals, sunflowers and potatoes will survive cultivation with a harrow that kills delicate, shallow-rooted weed seedlings. Crop damage will vary with soil type, weather at the time of tillage, the kind of crop and the depth of seeding. Tillage will be most successful on moderately deep, firm soil where deeper seeding occurred.

Cereal crops seeded 8 to 10 cm deep, and at rates 25 per cent greater than normal can be cultivated with a harrow or rod weeder before crop emergence for the control of weed seedlings that have just emerged. This operation is risky and should be done only as a last resort. The concerns are crop injury and increased disease from deep seeding. Cereal seed should be treated with a fungicide to minimize seedling diseases. Tillage before crop emergence should be less than 5 cm deep and must be done before crop sprouts are 2 cm in length. This will usually be within three or four days of seeding. The best weed control occurs when the soil surface is dry.

With post-seeding tillage, some crop loss is inevitable and should be accepted by the producer if this practice is followed.

Post-emergence tillage

Wheat and barley seeded 8 to 10 cm deep and up to 25 per cent heavier than normal can be harrowed after emergence. Till at the 1 to 4 leaf stage before tillers form. Light harrows can be pulled slowly and parallel to the seed rows. Post-emergent tillage with a harrow may delay crop maturity by a minimum two or three days. Check crop plants during tillage. Irreparable damage will occur if crop roots are loosened, broken or damaged. Avoid tillage if the crop is under stress. In a dry spring, this operation will cause more damage than the potential damage caused by the weeds. Generally, barley is more susceptible to damage than wheat. Post-emergent harrowing in fields with heavy trash

cover is not recommended because straw will clog the harrows and damage the crops excessively. Herbicides are a better alternative in most instances.

Inter-row tillage

Tillage can reduce weed populations in row crops such as potatoes and sugar beets. The first tillage should be early and shallow. Subsequent passes can be made if required. Take care to avoid crop injury.

Fall tillage

Seedlings of winter annuals and some perennial weeds can be controlled with early fall tillage. Use a blade cultivator in the Brown soil zones to maintain stubble. Field cultivators can be used in the other soil zones. If stubble is sparse, avoid fall tillage and till early in the following spring. The time of fall tillage varies with the weed species. In general, fall tillage is done between crop harvest and soil freeze-up. Both fall tillage and a fall application of herbicide are very effective on winter annuals and should be part of most weed control programs.

Grazing

Grazing serves the same purpose as mowing in weed control. The main reason for mowing weeds is to prevent seed production. To be effective, grazing must also prevent seed production. Therefore, the age of the target weed is an important consideration in a grazing program. Weeds are most palatable when they are young and become less palatable with age. Grazing should be initiated when weeds are still palatable and before seed formation.

There are few situations where grazing will accomplish as much as mowing. This will depend on the target weed, the grazing system and the grazing animal. Many grazing schemes do not provide effective weed control because grazing animals are not available at the appropriate time, and fencing and management are inadequate or inappropriate to ensure that top growth and seed production are curtailed.

Grazing system

The grazing system should reduce the grazing animal's choice as much as possible. Systems that employ herded sheep and goats and short-duration grazing with cattle have been used successfully. Short duration means a high number of animals per unit area for a short time.

Selectivity is governed by the palatability of weeds to the grazing animal. Palatability decreases with the age of the plant. Therefore, you should start to graze early in the season when weeds are most palatable.

Grazing animal

When choosing a grazing animal, consider the species of

weed, the maturity of the weed, the availability of animals for grazing and the nutritional requirements of the animal. Each animal species tends to have a characteristic, preferred diet.

Generally, cattle and horses are grazers and select a diet dominated by grass and grass like plants. As an example, cattle and horses are ideal when the target weed is quackgrass or downy brome. Horses may select for quackgrass over Russian wild-rye. Horses avoid Russian wild-rye when other forage is available.

Goats are browsers and select a high percentage of woody material in their diet. Goats select 40 to 80 per cent shrubs in their diet on North American range lands. Alberta Public Lands have used goats on tame pasture to reduce sucker growth of aspen.

Sheep are intermediate feeders and select more broad-leaved plants, including many weedy plants. Sheep avoid tall plants, litter and tall grass. Sheep can modify their diet to include more browse or grass than other domestic animals. Sheep are used more often than other species to harvest weedy plants, and may be the best animal to try on many problem weeds.

Trap Strips

Crops especially attractive to insects may be grown in strips around fields. Here the pest insects can be concentrated and killed with insecticides or cultural practices. These attractive crops may simply be the same crop seeded at a different time or may even be a volunteer crop or weed. For example, corn borer adults lay eggs in the tallest plants. Trap strips seeded earlier or to a faster maturing variety, or planted next to a grassy strip, tramline or headland, concentrate corn borers and provide efficient control for the rest of the field.

Trap strips are also effective against wheat stem sawfly. Sawflies will fly only as far as necessary to lay their eggs. If trap strips of a resistant, solid-stemmed variety are planted around the perimeter of a field, sawflies will lay their eggs in this strip. Larvae do not survive in the solid stem. Sow trap strips for sawflies earlier than the main crop so that the stems will be more mature and thus more attractive to egg-laying females.

Bromegrass provides a permanent trap for sawflies. Sawflies readily lay their eggs in bromegrass, but grass also harbors parasites that control sawflies.

Trap strips reduce erosion and increase soil moisture and over-winter survival of fall crops and perennial crops.

Fire

Pest control with fire is not recommended. It is often ineffective because the temperature at ground level is seldom high enough to affect pests in the soil. Fire destroys crop residue and organic matter that could be incorporated into the soil. The destruction of the crop residue with fire may leave the soil susceptible to erosion. Fire may be particularly destructive to beneficial insects. Fire might not kill healthy larva and pupa of pests that overwinter beneath the soil but may kill beneficial insects overwintering near the soil surface.

PRINCIPLES OF BIOLOGICAL CONTROL

Biological control is the use of living organisms to regulate and reduce the effects of unwanted living organisms. Biological control organisms include insects, diseases, birds and mammals.

Background

Because of natural mortality, most of the living organisms in the world do not overwhelm the environment around them. In effect, the farmer has to control only the “leftovers”; that is, those pests that survive natural control.

Unfortunately, farming practices are often detrimental to natural control of pest species. Cultivation, wetlands destruction and monocultural crops leave little habitat for the diverse species that keep each other in balance. For example, many of the worst insect pest outbreaks in the province are in southern Alberta. The soils are low in organic matter and moisture and support a simple biological community. Cultivation and irrigation in this area have disrupted the original biological complex. The resulting simple, unstable monoculture is vulnerable to colonization by pests. Outbreaks of serious insect pests are less common in northern Alberta where sloughs and potholes, trees and uncultivated land add diversity to the environment.

Farming also disturbs the natural balance between pest and predator by frequent tillage and pesticide applications, which destroy pest and beneficial species indiscriminately. Pest species often recover first, to reach destructive levels before their predators and parasites can build up again.

As well, new insect, weed and disease species have been introduced in agricultural seed and produce from other continents over the centuries. The natural control agents were left behind in the country of origin and the balance of survival tipped in favor of the pest in its new home.

Biological control makes use of natural pest control, whether native or from the pest's country of origin. Although biological control of pests is rarely feasible as the only pest control solution, it has gained a place in many integrated pest management systems and has the potential to be used in many more.

Strategies for Implementing or Enhancing Biological Control

Biological control does not replace pesticides and other methods of control. It is meant to be combined or integrated with preventive, physical and chemical controls in an overall strategy or system of control for one or more pests. For example, timely tillage, which removes the green growth on summer fallow to starve newly hatched grasshoppers, can be used in combination with the disease-causing agent *Nosema* in the crop and the pesticide Furadan along the edges of the field. This combination of approaches will minimize losses due to

grasshoppers. There are three general biological control strategies: classic biological control, augmentative biological control and conservation of natural enemies.

Classical biological control

Classical biological control is based on the premise that introduced pests have natural enemies in their country of origin which keep them in check. Key natural enemies are imported under strict quarantine guidelines and propagated for release. The natural enemy or biological control agent increases in numbers by its own powers of reproduction to maintain a self-sustaining population.

The goal of classical biological control is to establish a permanent population of one or more of these natural enemies in the pest population that will reduce and maintain the pest at a tolerable level. This type of control has excellent potential for weed control in Alberta; however, there are no economic incentives for private companies to invest in this process because the process can take several years and is then self-sustaining. Therefore, classical biological control programs depend on government support for research and implementation.

Classical biological control is more appropriate on non-cultivated land, such as pastures, rangelands, right-of-ways and non-crop lands, where a single, dominant pest species is troublesome. Economically, it is the preferred method of pest control on these types of land. The biological control agent should be left undisturbed to allow it to build-up in numbers and attack the pest problem. For example, the black dot spurge beetle is a viable option for the control of leafy spurge in pastures and rangelands. It will only survive and build-up in population on relatively undisturbed land.

Augmentative biological control

Augmentative biological control requires periodic releases of either natural or exotic biological control agents and falls into two categories, inundative and inoculative.

Inundative releases mimic a pesticide in that they are aimed at rapid reduction or elimination of the pest by one or more mass applications of beneficial organisms.

Inoculative releases generally rely on frequent, well-timed introductions of beneficial organisms to prevent the pest from reaching damaging levels. The agent may be applied as a spray (for example, bacterial, nematode, viral, and fungal formulations), or released at key points for self-distribution (for example, predatory mites and parasitoids). This type of control is generally short-term and must be re-applied on a seasonal basis. In Alberta this method is used extensively in greenhouse vegetable crops and interior landscapes, and to some extent by the outdoor vegetable and forestry industries, and for mosquito control in urban areas.

Mass production of the biological control agent is a prerequisite for this type of control.

While government agencies are often involved in collecting and evaluating the control agent and the initial rearing procedures for natural enemies, the responsibility for production and marketing lies with commercial companies. Some of the larger companies are now involved in all phases of producing biological control agents.

Augmentative biological control is more applicable in a high value cultivated crop, where rapid control or suppression of the pest is desired. The biological control agent is applied periodically and the control is usually temporary in the treated area. For example, BioMal is registered as a spray in cereal and oilseed crops for season-long control of round-leaved mallow.

Conservation of natural enemies

Conservation of natural enemies aims at modifying the environment to provide suitable food and shelter for existing beneficial organisms. A favorable environment for the natural enemies of pests is enhanced by shelterbelts with diverse shrub and tree species around and within fields, access to water, reduced tillage, and careful regulation of pesticide applications. Pesticide use can be modified by spot treatments and time applications to avoid peaks of predator and parasite abundance. Choose application techniques that prevent drift. "Soft" pesticides such as soaps and oils can be used. Provide artificial shelters for beneficial bats and birds.

Table 14. Examples of biological controls in use in Alberta

Pest	Biological agent	Type of control
Aphid	Wasp	Inoculative
Caterpillar	B.T.	Inundative
Leafy spurge	Black dot spurge beetle	Classical
Round-leaved mallow	BioMal	Inundative
Crown gall	Dyggall	Inundative

Advantages of biological control

- Biological control can reduce the amount and frequency of pesticide use and reduce the risks of pest resistance, residues, phytotoxicity, applicator exposure and environmental hazards.
- Biological control takes advantage of expanded markets for pesticide-free produce.
- Biological control can provide on-going or long-term control because biological control agents are self-reproducing. As living organisms, they can seek, find and attack the pests, as well as multiply and spread. This provides reduced costs to the farmer in the long-term, particularly for classical biological control.
- Biological control can be used in areas inaccessible to pesticide application equipment and in environmentally sensitive areas.

Limitations of biological control

- Many biological control agents are host-specific, which is an advantage from the point of view of unwanted spread to non-pest hosts. However, several types of biological control agents may be necessary for a crop subject to attack by a wide range of pests.
- Biological control is a complex system. Familiarity with both pests and biological agents is necessary to effectively monitor interactions and to time introductions. Commercial suppliers of biological controls to Alberta currently do not offer a routine monitoring service, and government extension services may not have the expertise and time to supply adequate information. Farmers accustomed to the precise rates of pesticide application are often uncomfortable with the imprecision of suggested introduction rates of biological control agents. Demand for biological controls is often ahead of the information needed to ensure success.
- The quality of biological control agents has been variable, making it difficult to assess how effective they are. This situation may improve if the federal government decides to regulate this industry.
- The shelf-life of most biological control agents is short. Transportation arrangements and scheduling of applications must be precise.
- The time and expense required to develop biological control agents can be prohibitive. Careful screening is required to ensure that the agents will not affect crops, beneficial insects and other non-target plants and insects. Classical biological control agents may require five or even 10 years from the time of release to build up in population to the point where they are affecting the target pest. Even then, from two to six different classical biological control agents may be needed to significantly affect the pest.
- Biological control cannot be used against pests that are valued under some situations because biocontrol agents do not recognize boundaries. For example, a biological control agent would not be developed to control volunteer canola.

Steps Involved in Biological Control

The black dot spurge beetle provides an example of how classical biological control agents are obtained and used.

Should biological controls be used

A large infestation of weeds in an environmentally sensitive or inaccessible area such as along a river or stream bank is well-suited for biological control.

The black dot spurge beetle takes several years to build to an effective population. Thus, small isolated leafy spurge patches may be more effectively controlled by chemical or mechanical means than by biological control to prevent further spread of the weed. An infestation may also be contained by a herbicide application on the perimeter and a release of biological control agents in the middle.

Select a suitable release site

This can be critical for the establishment of the black dot spurge beetle and successful control. The release site should not be cultivated, mowed, sprayed, burned or otherwise disturbed for several years after the release of beetles. The population of spurge beetles must be allowed to build in numbers and become established on the infestation. Also avoid heavy grazing with the accompanying trampling. The black dot spurge beetle prefers a leafy spurge patch that is higher, drier and on sandy soil.

Obtain the biological control agent

Make arrangements to obtain the black dot spurge beetle as outlined in the section for biological control agents for leafy spurge.

Collect and transport the biological control agent

Black dot spurge beetles are collected as adults, usually just after they start to emerge in large numbers in early July. Use a sweep net to gather the approximately 500 spurge beetles needed for one release site. Carefully transfer the beetles into a separate insect-proof container, such as a large plastic pail or cloth bag. If the beetles are to be transported a long distance, place them in a cooler with ice or cold packs at the bottom for protection from over-heating. Do not place the containers directly on the ice.

Release the biological control agent

Release black dot spurge beetles within 48 hours of collection. Release the beetles on the plants at one spot in the centre of a suitable leafy spurge patch. Do not scatter them over a wide area. The release point should be well marked. Note landmarks for future monitoring of the release.

Check for establishment of the biological control agent

One year after the black dot spurge beetle release, a successful establishment will have the following characteristics:

- Beetles are at and around the point of release; or there is evidence of adults feeding on the leaves. Beetles are easier to find on leafy spurge plants in mid to late July on a warm, sunny day. A sweep net can aid in locating the adults to verify their establishment.
- The number of flowering leafy spurge shoots will be reduced within a radius of 1 to 5 m around the release point.
- The amount of grass and other vegetation growth may have increased in response to the reduction in leafy spurge growth.

Redistribute the biological control agent

Redistribution to new leafy spurge patches accelerates the dispersal of the beetles and thus their effectiveness, because natural spread is slow. Normally, spurge beetles should not be harvested from suitable release sites for at least three years to ensure their establishment and a buildup in population. In the first year of redistribution harvest only enough spurge beetles to release at a few new leafy spurge infestations. This may be in the same field or other locations.

Biological Control of Weeds

Biological control agents usually require extensive overseas testing and federal government approval; thus, an individual producer usually does not become involved in finding and importing new classical biological control agents. However, once the agents are established in Western Canada and available in sufficient numbers, they may be available to producers at no cost, for redistribution and release. Augmentative biological control agents, once developed, are usually commercially available.

Toadflax

Brachypterolus pulicarius - A small, shiny black beetle; 2-3 mm in length that feeds in the flowers.

Gymnaetron antirrhini - A small, dark grey weevil; 3-4 mm in length; feeds in the flowers.

Both insects can reduce the seed production of toadflax considerably. Both insects came from Europe early in the century and are now widely established in Western Canada. They can be spread by placing infested toadflax branches among the flowering shoots of uninfested toadflax.

Leafy spurge

Black dot spurge beetle (Aphthona nigricutis) - A small, light brown beetle; 3-4 mm in length; feeds on the leaves.

The larvae feed on the roots and do more to control leafy spurge than the adult stage of the insect. The black dot spurge beetle was introduced into Alberta from Hungary in 1983. It has increased in numbers at the original release site to over 400 spurge beetles per square metre. Reaching this high population level, it rapidly dispersed to a distance of over 1 kilometre from the initial release point. An accompanying decline in the amount of leafy spurge and an increase in the amount of grass and other vegetation has occurred at the release site.

Figure 1. Population density of black dot spurge beetle.

Figure 2. Dispersal of black dot spurge beetle.

Figure 3. Density of leafy spurge.

Of 110 redistribution releases of black dot spurge beetle made from 1988 to 1990 throughout southern and central Alberta, 71 releases (65%) established. The black dot spurge beetle establishes better on high, dry, and exposed leafy spurge patches where the soil is coarse and contains less organic matter. Thin stands on a knoll or south facing slope with sandy soil are ideal for black dot spurge beetle establishment.

Copper spurge beetle (*Aphthona flava*) - This beetle is very similar to the black dot spurge beetle but is reddish-gold in color. It affects leafy spurge in the same manner as the black dot spurge beetle does. Although the copper spurge beetle was introduced into Alberta from Italy at the same time as the

black dot spurge beetle, it has not increased in numbers as quickly. Twenty-nine copper spurge beetle redistribution releases were made in 1991 and 1992. This beetle seems to

prefer leafy spurge infestation on sandy or gravelly soil near water. More information is needed on the type of sites that are suitable for the copper spurge beetle.

Arrangements to obtain either spurge beetle can be made through the local agricultural fieldmen, district agriculturist, Soils and Crop Management Branch of Alberta Agriculture

Food and Rural Development or, when public lands are involved, the range management section of Public Lands.

Sheep - Sheep can acquire a taste for leafy spurge. If sheep are pastured in an area infested with leafy spurge, they will consume more leafy spurge than native grasses after two or three weeks. After four years of open herding of sheep along the St. Mary's River in southern Alberta, there is some decline in leafy spurge production and some increase in native grass production. The sheep prefer to eat the inflorescence and upper stems and leaves of the leafy spurge plants and can make good weight gains eating this nutritious forage source. Information on the grazing of leafy spurge by sheep can be obtained from the Public Lands Branch in Lethbridge.

Bladder campion

Tortoise beetle (*Cassida azurea*) - A flat, round, reddish beetle; about 10 mm in length; feeds on the leaves. The larvae feed on the young seed capsules, leaves and shoot tips.

The tortoise beetle, after careful evaluation to ensure it was species specific to bladder campion, was imported into Western Canada in 1989 from Austria. This insect has established successfully at four locations in Alberta. The tortoise beetle is relatively easy to rear and has a noticeable effect on the bladder campion. It is also available for redistribution. To obtain tortoise beetles, contact the local agricultural fieldman, district agriculturist, Soil and Crop Management Branch personnel of Alberta Agriculture or, when public lands are involved, the Public Lands Branch.

Round-leaved mallow

BioMal (*Colletotrichum gloeosporioides* f. sp. *malvae*) - This agent is a wettable powder formulation of viable spores of a fungus that occurs naturally. When this myco-herbicide is mixed with water and sprayed on round-leaved mallow, the highly concentrated fungus will attack and control the mallow. This is an example of augmentative biological control. BioMal was discovered, developed and registered in Canada. BioMal was the first biological organism for weed control registered in Canada. It is stored frozen and requires moisture for germination and penetration into the round-leaved mallow plant tissue. BioMal is marketed by DowElanco Canada Inc.

Brush

Goats - Goats have been successfully used to browse brush growth to improve cattle pasture. In one pasture, a stocking rate of 25 goats per acre was sufficient to defoliate 95 per cent of the targeted brush species in two weeks. Rose and aspen were the preferred browse species of goats.

Information on the use of goats to browse brush can be obtained from the Public Lands Branch in Sherwood Park.

Biological Control of Insects

Biological control employs natural enemies to reduce pest populations. Enemies of insect pests include pathogens (disease-causing organisms), predatory and parasitic insects, and insect-eating vertebrates.

Predatory insects, such as lady beetles, eat many kinds of pest insects. They are one example of insects that are predacious in both larval and adult stages. Blister beetles are predacious only as larvae; the adults are foliage feeders and can cause damage to legumes. Their importance as control agents must be carefully assessed before adopting control measures against them.

Insect parasites, such as ichneumon wasps and tachinid flies, eat only one host individual. These insects lay their eggs on, in or near the pest. The larvae usually develop inside the host and kill it when their own larval development is complete.

Pathogens include viruses, fungi, bacteria, nematodes and protozoa. Some pathogens are being developed commercially to replace or supplement chemical pesticides.

A knowledge of natural enemies is a primary tool in managing insect populations. In effect, a farmer controls only the "left-overs", the pests that survive the natural rigors of weather, diseases, predators and parasites. Farmers need to know which insects are beneficial so that they are included in pest control decisions and not inadvertently destroyed. For instance, bee flies are often numerous during grasshopper infestations; their larvae eat grasshopper eggs. Many farmers are unable to recognize them and try to control them. If beneficial insects are abundant in an infested field, the infestation may soon come under control. To obtain the greatest benefit from natural enemies, farmers should choose control methods that are the least harmful to the beneficial insects.

Pathogens

Insects are infected by many disease-causing organisms (pathogens) including viruses, fungi, bacteria, nematodes and protozoa. Some pathogens are quite common and cause widespread infection in insect populations. Other pathogens are rare. The effect on the host insect may be severe and their populations can be decimated. On the other hand, some pathogens may produce only mild, long-term effects. Pathogens vary in their specificity to the host. Some viruses will infect only one species or several closely related species. The bacterium, *Bacillus thuringiensis* (or **B.t.**), on the other hand, infects the larvae of several species of butterflies and moths.

B. t. has been produced in commercial formulations since 1958. Sold under the names Dipel, Novabac, Thuricide and Biotrol, it provides control of many butterfly and moth larvae such as cabbage looper, imported cabbageworm, alfalfa looper and diamondback moth. When **B.t.** is applied with insecticides, lower rates of insecticides can be used and more insect enemies of the host remain to provide continuing control.

B.t. is now registered for use on ornamental and shade trees for spruce budworm, gypsy moth, cankerworm, fall webworm and tent caterpillar. In agriculture, **B.t.** is mainly used against imported cabbageworm, cabbage looper and diamondback moth larvae on cabbage family vegetables — cabbage, broccoli, Brussels sprouts, cauliflower, kale and turnip greens.

B.t. attacks the larval gut and must be eaten by the insect to be effective. Within a few hours of eating **B.t.**, larvae stop eating and death usually occurs within 12 to 72 hours. **B.t.** is applied at the first sign of infestation and at weekly intervals thereafter if necessary.

Vertebrate predators

Domestic birds - Flocks of poultry, especially turkeys, are helpful against climbing cutworm, armyworm, and even grasshopper infestations, with the added benefit that little additional food should be necessary for the turkeys that season. In California, from 175,000 to 200,000 domestic geese are used each year to control insects and grassy annual and perennial weeds in fields of cotton and various other crops. Geese have controlled weeds in strawberries for many years. Chicken ranchers near Riverside, California use young male chicks to control flies around the cages of laying hens.

Wild birds - Wild birds are also extremely beneficial in insect control. A study done by the United States Department of Agriculture found that enormous numbers of harmful insects were eliminated by birds; the diets of some of our most common birds such as swallows, house wrens, kingbirds and phoebes are 90 to 100 per cent insects. The American study determined the percentage of seeds, fruits and insects in the diets of birds. But the numbers of insects consumed are revealing. For example, a chickadee can eat up to 4,000 insect eggs a day; a wren family feeding its young will consume more than a thousand insects a day; a tree swallow will eat 2,000 to 3,000 mosquitoes a day. Also, birds are at the height of their feeding activity from April to late July — exactly the period when the farmer needs help.

To have the on-going pest control that is provided by birds, the farmer should provide habitat, such as bushes and trees (necessary for nesting and for protection from enemies) and plantings of seed-bearing trees or bushes for a continual food source. A source of water is also necessary. Undisturbed grass is important. Many of our most beneficial birds nest on the ground (in undisturbed grass) or just a few inches above the ground (in woody plants) and also feed on the ground. Thus, an effort should be made to provide not just tall trees, but brush and grass as well. The grass should be left undisturbed until late July, after young birds have fledged.

Other vertebrates - It is customary for farmers to look upon

rodents and other small mammals as pests, but these animals are very helpful in insect control.

Moles and shrews destroy great numbers of soil inhabiting insects, principally white grubs and cutworms of various kinds. Studies done at the end of an outbreak of larch sawfly in the Maritimes, showed that predators had destroyed 48 per cent of the sawfly cocoons. (The insect pupates in the ground and forest litter.) Small mammals caused half the mortality and insect predators caused the remainder. In areas where sawfly cocoons have been abundant for several years, 40 to 50 per cent of the cocoons are generally destroyed by small mammals. In one area of New Brunswick, 80 per cent of sawfly cocoons were opened by mammals.

Nocturnal webworm, cutworm and armyworm moths are subject to predation from a very efficient night-flying insect predator, the bat. Unfortunately, bat populations have largely declined. Recent studies of a huge bat colony in southern Texas showed that bats ate 115,000 kilograms of insects each night!

Toads, frogs, salamanders and lizards are often overlooked as insect predators, as are mice and skunks. Examination of the droppings of skunks have shown that 85 per cent of their food consisted of range caterpillar pupae. Similar figures occur for other small to medium-sized mammals.

Modern farming has created habitats for pests by establishing monocultures and by eliminating wildlife. Complete dependence on chemicals for insect control is not a sound policy. Future pest management practices will have to rely on a variety of methods.

Practices That Harm Beneficial Insects

Farmers with an understanding of the natural enemies of a crop pest can attempt to provide the growing and overwintering conditions required by them. They can also avoid harmful farming methods. If a farmer knows that a pest overwinters in the soil (as eggs, or pupae, for example) and that beneficial enemies of the pest overwinter in the crop trash, then burning or turning under the crop trash will likely free the crop pest from its enemies. The solution is to leave the crop trash in place until spring.

Similarly, when crop pests are mobile (such as adult, winged insects) and their enemies are not, then harvesting destroys the beneficial insects while the pest insects simply move and infest another crop. In this instance, strip harvesting is preferable. The crop is harvested in alternate strips and when some re-growth of the harvested strips occurs, the final strips are harvested. This method is particularly useful in alfalfa.

Avoid harmful cultural practices

Cultural control is a valuable part of pest management, but practices such as plowing, disking, mowing and burning can be harmful to beneficial insects. The effects of such operations must be fully evaluated, and harmful practices eliminated or modified if possible. For example, burning or burial

of surface litter, while beneficial for some diseases, weeds and insect problems, also destroys the habitat for overwintering populations of beneficial insects such as ladybugs. A farmer equipped with a thorough knowledge of the organisms that are present can make a decision on a field operation only after a careful scouting of the field.

Temporary habitat for birds can be maintained by leaving grass or hay unmowed until July 15 when most ground nesting birds have fledged their young.

Weed control

Weed control practices have reduced the effectiveness of some parasitic flies and wasps. The elimination of host weeds plus the possible toxicity of herbicides to the insect parasites might cause an increase in crop damage. Complete abandonment of field-edge weed control cannot be recommended, however, because faster growing weeds crowd out desirable species. To achieve the biological control potential of parasites that live there, a herbicide program must be developed which favors the continuous maintenance of field margin species.

Protect natural enemies from pesticides

The amount of pesticide to use in a management program can be based on the degree of pest control required to prevent economic loss. Other considerations are the readiness with which the pest can be controlled by natural enemies, destruction of the pest's food hosts by cultural methods, the need to maintain a reservoir of pests as food for natural enemies, and the conservation of natural enemies related to the entire crop and pest complex. A high level of control may only be necessary for a few, very destructive pests. Avoid the use of high dosages to overcome inadequacies of timing or coverage.

In some cases the use of pesticides cannot be eliminated. If pesticides are in general use in the area then, even if a farmer chooses not to use pesticides, his farm may be affected by their use. For these reasons a short section on protecting beneficial insects from pesticides is included here.

Pesticides can increase pest numbers - Pesticides can interfere with the natural control of secondary (non-economic) and primary pests. Whether organic or inorganic, stomach poison or dormant oil, dust or spray, insecticides can have the opposite effect from that intended. One of the most striking examples of this is from California where DDT was used to control pests in 1946 and 1947. A ladybug, the vedalia beetle, had long provided outstanding biological control of cottony-cushion scale (a relative of aphids) on citrus. When DDT was introduced, the beneficial vedalia beetles were killed by the sprays, while cottony-cushion scales (the primary pest in the orchards) were not. Serious outbreaks of scale resulted.

A secondary pest, red-banded leaf roller, rose to economic levels after various organic insecticides were used against codling moth and other apple pests. In this case, the natural

enemies of the pest were destroyed by pesticides.

Most insecticides are toxic to insect predators and parasites as well as (or sometimes even more so than) the pests. Therefore, it is important to modify or eliminate pesticide treatments to minimize their effects on beneficial insects. There are at least two ways to use insecticides selectively to conserve natural enemies.

Use selective insecticides - Use an insecticide that is toxic only to certain insect pests. Many early insecticides had a degree of selectivity. The arsenicals, for example, killed insects with chewing mouth parts. Predators, parasites and insects with piercing-sucking mouth parts such as aphids and leafhoppers were not killed. Although chlorinated insecticides were at first considered to be effective against virtually all types of insects, it was later found that DDT, toxaphene, and several other chlorinated insecticides were quite selective. Toxaphene, for example, is not highly dangerous to honey bees.

The new synthetic organic insecticides kill insects through various combinations of contact, ingestion and fumigant action. They are generally less selective, however, and predators, parasites and pollinators are more seriously affected. Some newer insecticides have selectivity. Systemic materials such as demeton (Systox) can be used to control harmful insects and preserve beneficial insects. Once demeton is absorbed by plant foliage, it no longer kills by contact. Some short-lived materials, such as TEPP, are highly toxic to the active insect stage at the time of application. However, insect eggs and pupae, and transients such as pollinators not in the field during spraying, are frequently unaffected. Several of the organophosphates can also be selective. Trichlorfon (Dylox) can be used to control lygus bugs and caterpillars with relatively little harm to predators and pollinators.

Use selective application methods - Insecticides can be made selective by changing the application method. Such changes may take into account the activity patterns of insects. Many insecticide labels now advise that spraying in the evening will lessen the impact on honeybees because most will have returned to their hives. Insects have food preferences that may be used to advantage. Wheat bran laced with insecticide or a combination of insecticide and pathogen is effective for grasshopper control. Not only do grasshoppers readily eat the poisoned bran bait but less chemical is needed to achieve the same control as spraying would provide. Beneficial insects are left unharmed.

Thus, timing of application, dosage and formulation can be modified for improved selectivity of even broad-spectrum pesticides. However, changes in use patterns do not insure that pesticides are favorably selective. A treatment may have desirable selectivity in one situation and be highly toxic to important natural enemies in another. Each material must fit the particular needs of the agro-ecosystem. Improved timing is usually necessary to compensate for the reduced killing power as dosages are reduced to achieve selectivity.

Use pesticides to prevent economic loss - In deciding the

amount of a pesticide to use, consider the potential for control by natural enemies or cultural methods. Use pesticides only when the cost of their use is less than the value of the crop lost if pesticides were not used. Control may be necessary for only a few key pests. High dosages may be required to overcome inadequate timing and coverage, or pesticide resistance. The need to maintain a reservoir of pests as food to maintain the natural enemy populations, and the conservation of natural enemies themselves are important pest management concepts.

Reduce pesticide dosages - Reduced dosages are commonly used for immature stages of insect pests. Common grasshopper chemicals may be registered for application at one-third to two-thirds of the adult rate. Applying these reduced dosages at the wrong time, when most of the population has reached the adult stage, will produce poor results. Information on optimal spray timing is crucial to any pest management program.

Maintenance of diversity

The farmer interested in stabilizing an insect pest problem should manage the enemies of pests as well as the pests. A mixed-farm habitat, with a blend of crop land in rotation, pasture, woods, some wetland and other natural areas, encourages a diversity of species. If the terrain is not varied, then shelterbelts, hedgerows and some permanent grass areas in headlands and near water sources will encourage predators and parasites of insects to remain nearby. A diverse plant community provides predators with needed hosts and other sources of food, overwinter sites and refuges. Diversity and stability in nature go hand in hand.

Maintain natural wild flowering plants and grasses, along with trees and bushes in areas surrounding the crop. Plantings of native wild flowers and grasses are especially beneficial because they are adapted to our climate and growing conditions and provide a season-long source of pollen and nectar for beneficial insects.

So-called waste or wild areas need not be altered, cultivated or controlled, as long as they are not dominated by a weed or insect pest. Some tolerance of low levels of pests is advised because without pests, there will not be a breeding area for natural enemies.

Provision of food and shelter for natural enemies

The maintenance of diverse plantings on the farm helps provide food and shelter for beneficial insects. There are some practices that aid the predators and parasites of insects. One is to provide a plentiful and continuous source of pollen. Studies have shown that there was greater parasitism of tent caterpillar eggs and pupae and codling moth larvae in Ontario orchards that were not sprayed and had many nectar producing flowers, compared with orchards containing few flowers.

In California, a predatory mite controlled the avocado brown mite when pollen was dusted on the plants but did not control the pest when pollen was omitted. Thus the planting or maintenance of native wild flowers and grasses can be beneficial to

the predators and parasites of pest insects. Vegetables and weeds of the parsley family are particularly useful for attracting beneficial insects. Flowers of carrots, anise, dill, parsley, coriander, parsnips and wild parsnips attract beneficial wasps. Willow trees provide an early source of pollen in the spring.

As well as pollen-producing flowers, plantings of seed and berry producing trees and bushes are helpful. Currant bushes, Nanking cherry bushes, crab apple trees, Manitoba maple or mountain ash trees, and caragana hedges all provide protective cover and food for insects, small mammals and birds. Nesting sites, drinking water, bushes and undisturbed grass can encourage the buildup of a bird population.

It is possible to provide artificial food and shelter for beneficial insects. Although it is not yet common practice, some agrologists are using artificial food supplements sprayed on crops to encourage the population growth of beneficial insects. These sprays are often sugar or molasses based.

Artificial shelters can be provided for bats and birds. Bats help control night-flying moths, such as millers, which have few other predators. The little brown bat, native to Alberta, can be enticed to roost in artificial shelters near a water supply, although it may take the bats several years to accept the shelter. Bird boxes will boost the bird population. The right type, size and dimension of bird box should be used because birds have varied needs in housing. Most government wildlife departments have information on shelters and houses for birds and bats.

FIELD SCOUTING

Field scouting is the regular examination of fields in a prescribed fashion to measure pest levels. To properly scout for pests, you must know where they live, what they look like, and how to find and count them. This information is provided in the sections on specific pests. A combination of basic scouting procedures and a good knowledge of pest biology allows you to collect the information required to make sound pest management decisions. When scouting, you can also assess whether your management strategies are working, or in themselves, causing problems.

Why Scout Fields

Field scouting is an economically and environmentally sound prerequisite to pest management decision-making. No good is achieved by treating a pest where damage is insignificant. On the other hand, treatment when the damage is too far along is economically and environmentally irresponsible. A farmer can only collect the information needed to make timely management decisions by regular scouting. Regular scouting also prevents unnecessary treatments and reduces the uncertainty associated with pest management.

Scouting Timetable

The table on the next page shows when various pests common to Alberta can normally be found and treated.

Scouting Frequency

Scouting should be done weekly during the growing season and even daily when infestations approach economic levels or weather conditions favor rapid development of specific pests. With some plant diseases, daily scouting is necessary when it is warm and humid. With weeds, competition is normally most critical during the seedling stage, but this can vary with the species.

What to Look for

When scouting you should note all the pests and beneficial insects that you find. You want to detect problems that will affect this year's crop and future crops so you can make short- and long-term pest management decisions. For example, you want to detect a high population of grasshoppers so you can take action, but you also want to detect a low level of cleavers so you can keep the field in a cereal rotation to clean-up the problem.

Assess the overall appearance of the field, then examine specific plants including seed heads, stems, leaves and roots. Cut them open and check for signs of damage by insects and diseases.

Besides the pests themselves, you should watch for typical damage symptoms that are caused by pests and pesticides. These symptoms are not exclusive to pests and control products but may be caused by environmental and soil factors. The following

symptoms are commonly associated with pests and pesticide damage. Use them in recording your observations.

Field symptoms

spotty growth	yellowing
browning	loss of vigor
stunted growth	thin stand
differences due to topography	kinked
lodged	poor germination

Leaf symptoms

unusual color	cupped
loss of leaves	rolled leaves
crinkled	feathered
chewing signs	spotted
stripped	blotched

Flower and fruiting symptoms

wilted	deformed
improper arrangement	missing
branched	delayed development
clipped	aborted

Stem symptoms

twisted	kinked
broken	elongated
shortened	cracked
spotted	swollen
abnormal tillers	punctured
rotten	

Root symptoms

inhibited	tunnelled
rotten	swollen
chewed	

The Tools Needed for Scouting

The following items should be assembled in a carrying case for field use:

- clipboard
- record sheets
- tweezers
- 10X hand lens
- hand trowel
- pocket knife
- vials
- resource material
- sampling frame (0.25 m²)
- alcohol
- clear plastic bags
- paper bags
- sweep net
- sieve
- labels for identification
- flagging tape

Use these tools to collect samples, and to record, examine, and preserve them for reference or identification by your local district agriculturist, agricultural fieldman or provincial laboratory. You will find all these items are essential when you are on your hands and knees with a pest in your hand and no where to put it.

FIELD SCOUTING TIMETABLE

	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
INSECTS	<p>← Flea beetles</p>	<p>→ Cutworms</p> <p>← Red turnip beetle</p> <p>← Alfalfa</p> <p>← Aphids</p> <p>→ Grasshoppers</p> <p>← Thrips</p> <p>← Wireworms</p>	<p>→ Alfalfa curculio</p> <p>→ Alfalfa plant bug</p> <p>← Alfalfa weevil</p> <p>→ Sweet clover weevil</p>	<p>→ Diamondback moth</p> <p>→ Armyworm</p> <p>→ Orange blossom wheat</p> <p>→ Wheat stem maggot</p> <p>→ Blister beetles</p> <p>→ Pea aphid</p>	<p>→ Flea beetles</p> <p>→ Bertha armyworm</p> <p>→ European cornborer</p> <p>→ midge</p> <p>→ Wheat stem sawfly</p> <p>→ Lygus bug</p>	<p>→ Sweet clover weevil</p>
DISEASES	<p>→ Seedling blight</p> <p>→ Blackleg</p>	<p>→ Common root rot of cereals</p>	<p>→ Alternaria blackspot</p> <p>→ Loose smut</p> <p>→ Leaf diseases of cereals</p>	<p>→ Sclerotinia</p> <p>→ Covered smut (bunt)</p> <p>→ Verticillium wilt</p>		
WEEDS	<p>→ All weeds in cultivated land</p>	<p>→ Perennials</p>	<p>→ requiring treatment in bud stage</p>	<p>→ Winter annuals and perennials</p>		
RODENTS	<p>→ Pocket gophers</p> <p>→ Ground squirrels</p>				<p>→ Pocket gophers</p>	

Sampling square

A sampling square can be made from 1/4" iron rod bent to form three sides of a square. It is used to mark out a specific area of a crop for sampling. The rod should be sprayed a bright color and marked with flagging tape so it is easy to find if placed or dropped in a crop. Generally 0.25 m² is used as a sampling area. To make a three sided 0.25 m² sampling square a 150 cm length of wire is required. The square is only three-sided so it can be slipped into a standing crop parallel to the ground rather than dropped down through the canopy.

Number of samples

Follow the sampling procedure described in the pest specific write-ups that follow. In situations where the exact sampling procedure is not provided use the following rule of thumb:

- In fields of less than 100 acres, check a minimum of five locations.
- In fields of greater than 100 acres, check a minimum of 10 locations.

Scouting Patterns

Scouting gives a representative, objective assessment of the pest situation in a whole field, not just in the edge, centre, high or low areas. The shape of the field, its ease of access, and the nature of the pest's typical distribution pattern all play a part in deciding how to scout a field. Other field variables such as organic matter or soil structure may affect the weed species in different parts of a field.

There are several possible scouting patterns that can be used when scouting fields. These options are based on various pest distribution types and field configurations.

In some instances, it may be necessary to combine two or more patterns. This is especially true when the field is very uniform, little is known about the pest, or a control decision is being contemplated but you are not totally confident in a sampling program. A thorough sampling allows a producer to make a sound decision, and perhaps save money.

For example, wild oats are generally throughout a field while flea beetles, or grasshoppers are most prevalent along field margins. With flea beetles and grasshoppers, the scouting pat-

tern can change depending on the time of year. Which scouting pattern you select may also be influenced by where you enter the field and where you leave it.

Pattern I - Used when pests are uniformly distributed

When scouting for pests with this type of distribution, the sampling sites should be evenly distributed across the field excluding obvious influencing factors such as field edges, hills and Solonchic areas. These patterns typically look like an X, Y, W or Z. Pests that fit this pattern include stinkweed, wild oats, leaf diseases, aphids, diamond-back moth, bertha armyworm, root maggots, alfalfa weevil, corn borer, and lygus bugs.

Pattern II - Used when pests are unevenly distributed

Use this pattern for pests associated with specific high, low, wet, dry, Solonchic and high organic matter areas. Pests that fit this pattern included redbacked and pale western cutworm, thistle, quackgrass, root rot and tansy. If scouting for pests that inhabit specific types of habitat, the sampling should be concentrated in those areas.

Profile of Field (Side View)

Pattern III - Used when pests are at edges of fields

Use the following pattern for pests that are expected to appear at field edges first. Sample those pests by walking in the field edges, fence lines or ditches. Pests that fit this pattern include flea beetles, grasshopper, red turnip beetle, scentless chamomile, tansy and Canada thistle.

Basic Information to Aid in Scouting

A scout should be familiar with stages of the crop and weeds and should be able to assess what percentage of leaf material

is infected by disease or consumed by insects. The following charts provide this reference material.

The Feekes and Zadoks scales define the growth stages of a relatively uniform cereal crop. Completion of these growth stages by the cereal crop will be influenced greatly by soil temperature, moisture, air temperature and day length. For example, stages 2-5 in the Feekes scale may take 5 or 6 weeks, whereas stages 6-10 may be completed in 2-3 weeks.

To establish the growth stage of a cereal crop using either of these scales, collect a random sample of plants and determine the level of growth attained by the majority of the plants. Under good growing conditions, examination of up to 10 randomly selected plants may be appropriate. Larger samples may be needed for determining the growth stage when germination is uneven and soil moisture levels are low.

Precise timing of the application of an agrochemical, be it a fungicide, growth regulator, herbicide or supplemental nutrient, is of vital importance in maximizing the desired effect on the target crop. An application based upon physiological growth stage, and not farming practices based on calendar days, will ensure the best result from the agrochemical.

Basic Weed Scouting

The goal of weed scouting is to assess the infestation level of

known pest weeds and detect new weeds that may be at very low levels so action can be taken to control or prevent them from becoming an economic concern. In some cases, early detection of a weed can make eradication possible.

Begin scouting as soon as weeds appear in the field and continue until freeze-up. Record stages of growth of both broad-leaved and grassy weeds and the numbers per square metre of each weed.

Frequently, all scouting patterns must be used since weed habitat can be very species specific. Each field usually requires a pattern for a uniform sample and samples in low areas and field margins or ditches to assess immediate or future risk from problem weeds left uncontrolled.

Detailed counts of the numbers of weeds per square metre provide the ideal record of a weed problem. If this is not possible, the following rating system may be useful:

Group I - Wild oats, stinkweed, wild buckwheat, lamb's-quarters, redroot pigweed, hemp-nettle, smartweed, rape, wild mustard, Russian thistle, tartary buckwheat, cow cockle, shepherd's-purse, kochia.

Light	Medium	Heavy
1-10 plants/m ²	10-30 plants/m ²	30 or over plants/m ²

CEREAL GROWTH STAGES

Group II - Chickweed, green foxtail, corn spurry.

Light	Medium	Heavy
1-20 plants/m ²	20-70 plants/m ²	70 or over plants/m ²

Group III - Canada thistle, sow-thistle, dandelion

Light	Medium	Heavy
1-2 plants/m ²	2-10 plants/m ²	10 or over plants/m ²

These definitions can be used to help standardize ratings. With experience, infestations can be visually estimated. These groupings are based on the competitive characteristics and life cycles of these weeds.

Basic Insect Scouting

The objective of scouting for insects is to identify the insects present in your fields, determine which ones are or may become a problem, and assess numbers and damage so a decision on action can be made. This means sampling for insects and examining plants. Often both insects and diseases can be assessed at the same time. This may vary depending on whether you are sampling just when seedlings are emerging or when the plants are 10 cm tall. Cutworms in the first case would be very small and difficult to find but large and easy to find in the second case. For details about specific sampling techniques for pest insects, refer to the section on insect species.

Foliage damage

Very mobile insects such as grasshoppers are counted by estimating the number per square metre. Less mobile insects, such as armyworms and webworms, are shaken from the plants onto the ground and counted. This provides an accurate quantitative assessment of insects per 50 cm X 50 cm of crop. (Multiply by 4 to determine pests/m²).

For insects such as lygus bugs and beneficial insects, calculate the insect numbers per sweep with a sweep net as the sampling technique. Since many insects are very mobile or small and difficult to see, the sweeping technique is very useful.

A sweep is made by swinging the net at arms length through the crop canopy so the top of the net is at crop height. If there is little canopy or the crop is short, sweep close to the ground. One sweep can be either a 90° or 180° pass through the crop. Take two steps forward between sweeps so the sweeping activity does not influence the catch in your next sweep.

At the end of the sweep, swing the net quickly back and forth through the air to force the insects to the bottom of the net. Quickly grab the bag about 15 to 20 cm from the bottom to confine the insects and prevent escape.

Always take a consistent number of sweeps per sample. Count the insects in the net as you let them escape, or empty them into a plastic bag or bottle. The counting system you adopt will depend on how well and quickly you can identify the insects in your net, the number of species present and the total number of specimens.

Typical 90° sweep.

180° sweep.

Individual leaves, especially the top ones, should be examined for presence of insects and assessment of damage in addition to sweeping. The following illustration will help you to estimate leaf damage. With insects such as thrips, the damage is done to the leaf sheath and flag leaf. Examine the entire leaf and the sheath for the insect and its scrapping damage. Disturb the leaves as little as possible to prevent insects from falling off the leaves.

Seed head and pod damage

When crops are in seed, always examine the surface of the head or pod for sign of feeding or puncture by insects. Open seed pods to examine seeds. Insects such as the lygus bug only leave signs of damage on the seeds. With canola or alfalfa, you may find seeds shrivelled when a pod is opened. This is frequently caused by lygus bug.

Stem damage

Look for puncture marks on the stem surface, then split the stem from top to bottom. Examine the inside of the stem for insects such as wheat stem maggot or wheat stem sawfly. Also examine the stem right at the root crown for signs of insects such as Hessian fly pupae.

Root damage

Always dig up the roots, clean away the soil and look for

insects such as cutworms and maggots. If there are signs of damage, but no insects are present, sieve the soil around the plants to find the causative agent. How carefully you must examine the soil will depend on the size of the insect. In some cases, you may have to thinly spread the soil on a black plastic garbage bag to find the pest.

Basic Disease Scouting

Whenever scouting, be aware that symptoms of plant disease problems may be caused by weather, fertilizers, deficiencies, herbicides and soil problems. In many cases, the cause of the symptom is not obvious. Very close examination and a laboratory culture or analysis are required to confirm the causal agent. Basic examination techniques and details for specific diseases are given in the section on specific plant diseases.

Root sampling

If there are no obvious symptoms on plants, examine plants randomly and look for lesions or rots on roots and stems. Always check plants that appear unhealthy. It is often necessary to wash the roots with water to examine them properly. If the roots are well developed, cut into them to examine the roots for internal infections.

Leaf sampling

Examine all leaves and sheaths on each plant for lesions and determine the amount of leaf infection. Leaf diseases cause most damage during the seedling and flowering stages of plant growth.

Stem and head sampling

Carefully examine the stems, heads and pods of plants for signs of fungal material or lesions. The stems, pods and heads should be split or taken apart and examined for discoloration caused by fungi and bacteria.

Planning is required to achieve optimum weed control at the lowest cost. The following factors must be considered:

- availability of equipment and labor
- types of weeds present
- soil type
- extent of the infestation
- cropping system
- other environmental conditions.

Because these factors cannot always be predicted, the strategy must be flexible. This section describes general principles of weed control, followed by guidelines for control of specific weeds.

Weed Biology

To develop control methods, the biology of weeds must be understood. The main strategies in controlling annual weeds are to prevent seed production and reduce the number of weed seeds in the soil. With perennials, destruction of the root system is the key to control. Weed control techniques exploit the biological differences between the crop and the weed and use the weaker phases of the weed's life cycle to assist with control.

Life cycles and control strategies

Annuals- There are two types of annual weeds. Summer annuals germinate in the spring, produce seed during late summer or fall, and then die. Examples are wild oats, kochia and green foxtail.

Winter annuals germinate in late summer or fall, produce rosettes that overwinter and continue growth early the following spring. Seeds are produced in the early summer. Examples are stinkweed, flixweed and shepherd's-purse. Some weeds are both winter and summer annuals.

Because annual weeds reproduce only by seed, control is simple. Kill the plants before seed production occurs and encourage seed germination when the weeds can be controlled and do not affect the crop. Most seedlings are easily destroyed by either cultivation or herbicides. This strategy can be thwarted by the tendency of these weeds to grow and mature quickly. Winter annuals often flower before all the spring snow has melted. The life cycle of annual weeds is similar to that of annual crops: they germinate, grow and produce seed along with the crop.

The following controls are recommended:

- Till the inter-row area in row crops.
- Use a harrow or rod weed set for a shallow tillage when weeds emerge before the crop.

- Use in-crop herbicide treatments when annuals are seedlings where appropriate.
- Use pre-seeding tillage to stimulate germination. Follow with weed destruction during the seeding process.
- Rotate the land to perennial crops.

Biennials- These weeds require from 12 to 24 months to complete their life cycle. In the first year a taproot and foliage are produced. The root overwinters and the shoot produces flowers and seeds in the spring. Biennials are controlled by fall or spring tillage or with timely treatment with an appropriate herbicide.

With increased production of fall sown crops and reduced tillage, biennial weed populations have increased. Examples are scentless chamomile, stork's-bill, and narrow-leaved hawk's-beard. Biennials can also be a problem in perennial forage crops or anywhere tillage cannot be used.

Perennials- These weeds persist for more than two years and have either fleshy tap roots, as in dandelions, or creeping root systems, as in Canada thistle. Both root systems store food throughout the season. Fleshy rooted perennials reproduce mainly by seed. Creeping-rooted perennials grow in patches and spread both by seed and roots.

Perennial weeds are less of a problem when fallow is included in the rotation than when annual crops are grown continuously. Under continuous cropping, creeping-rooted perennial weeds, such as Canada thistle, perennial sow-thistle, quackgrass and toadflax, become problems. These weeds can also be problems in weak perennial crops. To control perennial weeds, two possible strategies can be implemented: prevent seed production and deplete the food reserves in the roots. Repeated mowing, cultivation and treatment with an appropriate herbicide may help to achieve control.

Occasional light tillage will break up and scatter root pieces and produces new infestations. Intensive tillage or mowing throughout a season will strain the root energy reserves of the weeds. Timing of tillage is critical. Food reserves are generally low from the end of May until mid-July (see diagram). Tillage or mowing at the end of May will cause new shoots to emerge from dormant buds and the stand will appear thicker. This flush of new growth uses more energy than is produced so the overall food reserves are diminished. After three to four weeks, the weed stand should be mowed or tilled again, further depleting the root reserves. Weed control is accomplished by gradual starvation of the root system. The timely substitution of one or more of the tillage operations with a herbicide treatment could achieve a similar result without increasing the risk of soil degradation and erosion.

Fleshy-rooted perennials can be controlled by tillage. When the tap root is cut off the top growth will starve. Controlling fleshy-rooted perennial weeds is difficult in perennial crops.

Often the only option is to destroy the stand. Summer fallow or annual crops should follow perennial crops until the weeds are controlled. Control of perennials on roadsides is usually limited to mowing or spraying. Perennial weeds in pasture may be controlled by mowing, spraying and grazing. Sheep and goats will use weeds as browse. Over-grazing is the main factor responsible for the presence of perennial weeds in pastures. Rotational grazing systems are helpful in preventing the increase of perennial weeds in pastures.

Time of germination

Germination of weed seeds is influenced by temperature, moisture, depth of burial and dormancy of the seed. Knowing the date of emergence of weeds is helpful for scheduling cultivation, seeding, and spraying.

Time of flowering

Knowing approximately when a weed will flower enables you to control the weed or harvest the crop before viable seed is produced. Weeds produce viable seeds at varying stages of plant maturity, depending on the species.

Table 15. Percentage of seeds germinating from weeds cut at various stages of maturity

	Bud stage	In flower	Dead ripe
Sow thistle, common	0	100	100
Groundsel, common	0	35	90
Dandelion	0	0	91
Canada thistle	0	0	38

Dorscheid, L. A., and R. E. Schultz. 1960. Weeds 8(1):55-62.

Sow thistle seeds are viable when the weed is in flower. No viable seeds were detected when Canada thistle and dandelion plants were cut in the flower stage.

Seed dormancy

Dormancy enables weed seeds to survive for long periods in the soil without germinating. Weed seeds in the primary dormant state can remain alive in the soil and will not germinate even though conditions of temperature and moisture are ideal. Dormancy is broken naturally by the effects of micro-organisms, acids, salts, alternate freezing and thawing, and dry-wet cycles.

The length of time seeds remain alive in the soil is called seed longevity. Longevity of weed seeds varies with species. Knowing the longevity assists in planning crop rotations. For example, green foxtail seeds live for one to four years. A perennial forage crop grown for four years would deplete most green foxtail seed reserves. Proper weed control measures must be carried out to prevent re-infestation of the soil.

Weed and crop interactions

New weed problems evolve along with new crops and new cropping practices. For example, winter annual weeds have increased in winter wheat. Without fall tillage, winter annuals proliferate. Perennial weed populations have increased under continuous cropping systems. Without tillage or timely applications of herbicides, perennial root systems become well established.

The farmer's defense against new weed problems is to continue rotating the crops and control measures on a particular parcel of land. Crop rotation involves shifting among cereals, oilseeds, row crops, perennial forages and winter annual crops in a pre-determined manner. Volunteer crops are weeds because they compete with the seeded crop and reduce yields. Volunteer crop seed can usually be encouraged to germinate by shallow fall or spring tillage. In a dry fall, leave the seed on or near the soil surface, exposed to the elements. In spring, surviving seed can be stimulated to germinate by tillage. A second tillage with or just before seeding will destroy most of the volunteer crop seedlings.

Choosing Weed Control Measures

General considerations

Thorough weed control requires planning. It is difficult to plan strategies for controlling specific weeds without interfering with the control of other weeds, insects or plant diseases. Conflicts in recommendations occur and priority must be given to controlling the major pests.

Economics

Economic threshold densities are defined as weed densities at which the cost of weed control equals the cash return from the greater crop yield when weeds are controlled. At times, control of weeds does not pay.

Consider the crop stand and the time of emergence of weeds compared with the crop, in the economics of weed control. If the weeds get ahead of the crop, a greater yield loss can be expected than if the weeds emerge after the crop. As a rule of thumb, expect a 2.5 per cent loss for every day the weed emerges before the crop and a 2.5 per cent advantage if the crop emerges before the weed.

Late flushes of weeds such as green foxtail and stinkweed usually have minimal effects on the yield of competitive crops such as barley, wheat and canola. When the crop stand is poor, weeds cause greater yield losses.

What are the distribution, density and weed species in the infestation?

Estimate these by walking through the field and randomly counting and identifying the weeds present. The more counts made, the more accurate will be the estimation. This approach is most meaningful where strong competitors such as Canada thistle and wild oats predominate.

What is the likely crop yield loss caused by the weeds?

Crop yield losses caused by some weeds are known and are given under the individual weed listings in this publication. Estimates on yield losses from other weeds can be based on past weed problems.

What is the cost of the weed control measures? Calculate these costs including fuel, labor, equipment, additional seed and yield loss caused by delayed seeding or extra tillage.

How much of the lost yield will be recovered following control of weeds? This varies with the timing and method of control, the kind of crop, growing conditions and effectiveness of control. On average, assume about 85 per cent of the lost yield is recovered when a control method is carried out.

What is the market price of the crop? The market price of the crop is an important factor in determining the value of weed control. The higher the market price, the greater the likelihood that weed control will be economical.

What is the expected weed-free crop yield? This varies with soil type, fertility and climatic factors. Average yields for crops are available for the different soil zones in the province. Records from previous years will help you predict yields. As with the market price of the crop, the higher the expected yield, the greater the likelihood that weed control will pay.

What is the anticipated use of the crop? In certain instances where the crop will be used for hay, silage or feed, the presence of some weeds may not be detrimental. It is even possible the weeds can be beneficial. In other cases the presence of even a few weeds may degrade the crop or make it unsalable. The choice of crop for each field is thus very important in determining the losses that a particular weed will cause.

The presence of a weed that is locally prevalent may not be serious if the crop is being used for feed or is being delivered into the grains handling system. That same weed can make pedigree seed or forage crops unsalable in other regions not infested by that weed species. A local market for your crop makes a difference as to how much and which species of weeds are tolerable.

Conservation

Soil and water conservation- Several weed control practices can cause breakdown of soil structure, erosion, and loss of soil moisture. If erosion is a concern, tillage and summer fallow should be kept to a minimum. Green manure crops can improve soil tilth and water holding capacity and may compensate for some of the detrimental effects of tillage.

Loss of soil moisture- Tillage causes moisture loss that may reduce yield. Yield losses caused by uncontrolled weeds must be weighed against the potential yield losses caused by moisture reduction from tillage. Loss of soil moisture

in dry areas is of greatest concern. In these cases, tillage for weed control may not be feasible and alternatives should be considered.

One way to compensate for moisture loss is to increase moisture capture by managing winter snowfall, which constitutes 25 per cent of yearly prairie moisture. Standing straw strips used to trap snow increase soil moisture in the spring.

Erosion- Tillage that incorporates trash may leave soil exposed to wind and water erosion. To minimize this, leave as much plant residue on the soil surface as possible over winter. Effective weed control with minimal trash disturbance can be obtained with a rod weeder or a heavy duty or wide blade cultivator. A fall spraying operation can remove the need for any tillage operation.

Summer fallow fields are particularly susceptible to erosion. Tillage should be kept to the minimum. Alternating strips of crop and fallow will help to minimize erosion. These strips should run at right angles to the prevailing winds. Green manure can be grown to maintain soil organic content as well as reduce erosion. Shelterbelts will also help reduce wind erosion.

Maintaining organic matter- The organic matter content of soils decreases with tillage. Organic matter adds nutrients, maintains soil structure and reduces the potential for soil erosion.

To maintain or increase the organic matter content of a soil, keep tillage to a minimum. Fibrous-rooted plants such as perennial grasses contribute to soil organic matter. Green manure crops, continuous cropping rotations and increased levels of fertility will also help to build organic matter.

Weed Management in Specific Crops

Cereals

Spring wheat and barley- Weed populations may be reduced by destroying as many weeds as possible before seeding. Early spring tillage destroys winter annuals as well as annuals that germinate early and perennial seedlings. This early tillage also aerates and warms the soil and brings new seed near the surface. This will stimulate germination of a second growth of weeds that may be killed at or during seeding or through in-crop spraying. Packing, shallow seeding (into moist soil) and banding fertilizer will establish a competitive crop. Higher than normal seeding rates in heavily infested fields will favorably increase crop competition. The use of clean, plump, disease-free seed also increases crop vigor.

Spring tillage controls early emerging weeds and encourages germination of weed seeds. The flush of weeds that results will require a second tillage before seeding. Seeding and tillage can be performed in the same operation when moisture is limited. Control is most effective under hot dry conditions. Post-seeding tillage can be used on cereals in some areas of the province.

Tillage in the late fall destroys rosettes of winter annual

weeds. If tillage is not feasible, herbicides can be used. Tillage in the early fall encourages germination of some weed seeds. Fall tillage severs the roots of perennial weeds and exposes them to freezing and thawing, ultimately causing the root system to deteriorate.

Swathing the crop rather than straight combining is useful if late season weeds can be cut before their seed matures. After harvest a light tillage will increase weed germination if moisture is adequate. Annual weeds will be killed by frost. Winter annual weeds that germinate in the fall will require a late fall tillage, a fall herbicide application or an early spring tillage if they are to be controlled.

Winter wheat and fall rye- Weed control before establishing these crops is critical. A shallow pre-seeding tillage or an application of a top killing herbicide destroys weed seedlings.

Winter annual weeds cannot be controlled through in-crop tillage, but some species may be selectively controlled with herbicides. (See *Crop Protection with Chemicals*, Alberta Agriculture Food and Rural Development, Agdex 606-1).

Winter wheat and fall rye must be well established before freeze-up to avoid winter injury. Crops that overwinter poorly are poor competitors and will have little or no effect on winter and spring annuals. Few weeds, however, can compete with a good crop of fall rye or winter wheat.

Oilseeds

Canola and mustard- Cultural weed control in these crops is important because appropriate herbicides are not always available.

These crops should not be grown when perennial weeds are a problem. However, with the range of herbicides now available, canola can be grown when you are attempting to control Canada thistle and perennial sow thistle. Pre-seeding tillage destroys existing winter annual and grassy annual weeds.

The ability of oilseeds to compete with weeds can be increased by encouraging rapid emergence of the crop. This can be done by shallow, uniform seeding. Packing ensures good seed-to-soil contact and prevents excess moisture loss. Canola and mustard past the seedling stage are quite competitive with weeds.

Flax- Flax is a poor competitor. Even though annuals can be selectively removed from flax, their presence during the seedling stage can severely reduce flax yields. Seed flax on clean land.

Early, shallow spring tillage should be followed in two to three weeks by a combined tillage, seeding and packing operation. This operation controls weeds and provides a firm seedbed. Increasing seeding rates by up to 25 per cent can improve flax yields. Fertilizer should be banded for maximum effect because broadcast fertilizer applications benefit weeds as well as the crop.

Sunflowers- Sunflower seedlings are sensitive to competition, especially from perennial weeds. The main yield reductions are caused by competition from weeds about four to six

weeks after seeding. Land that is seeded to sunflowers must be clean because the crop is planted very early and cultural control before seeding is not always feasible.

For annual weed control, a sunflower crop can be harrowed anytime after seeding and occasionally even after crop emergence. A flexible-tined harrow causes less damage to seedling sunflowers than a spike-toothed harrow. Post-emergent harrowing can be done from the time the crop seedlings have two true leaves (the cotyledon "leaves" plus the first true set of leaves) until they are 15 cm tall. Harrowing works best on warm days when the sunflower plants are slightly wilted. Work across the crop rows. One harrowing reduces the plant stand by 3,000 to 5,000 plants/acre. Increase the seeding rate to compensate for this damage. Injury to sunflower roots from harrowing may increase the incidence of soil-borne root diseases.

Forages

Established perennial forages are good competitors. However, seedlings forages are susceptible to competition from weeds. Forage crop establishment and maintenance are the keys to producing competitive stands.

To ensure a competitive crop stand, clean seed should be sown on relatively weed-free land. Seed should be planted into a firm, well-prepared seedbed at the recommended rate and depth. Seeding is best done in the spring when moisture conditions are favorable. Forages seeded without a companion crop produce the best results in the long-term. However companion crops should be used when soil erosion or soil crusts are problems. Although companion crops suppress weeds, they also suppress forage seedlings and yield in subsequent years. Reduce seeding rates of cereals or flax when companion cropping is necessary; both methods will minimize the competition from the annual crop.

Mow companion crops at a height just above the forage seedling. This prevents smothering of forage seedlings and reduces production of weed seeds. Once established, forage crops will compete better than most annual weeds. Old forage stands may be rejuvenated by fertilization, a reduction in grazing pressure or use of appropriate herbicides. If these methods are ineffective, the stand should be cultivated and another crop planted. This crop should be one in which selective control of the problem weeds can be practised.

Pulse crops

Weeds can reduce pulse crop yields by up to 85 per cent. A limited number of herbicides are registered on pulses. Consequently, seed pulse crops into practically weed-free land. Field beans are generally seeded in rows and inter-row cultivation is possible. Fababeans and peas are usually seeded in solid stands, and therefore, require selective herbicidal control.

Shallow harrow or rod weeder operations can be used to control weeds after crop seeding but before emergence.

BLADDER CAMPION

Silene vulgaris

Courtesy of DowElanco

Life Cycle

A tap rooted perennial spreading by seed and severed root pieces.

Emergence

Seedlings emerge from shallow depths throughout the growing season.

Flowers

Flowers appear from mid-June through fall.

Reproduction

Seed

The main method of spread is by seed. Large quantities of seed are produced from mid-July through fall. Seed remains viable in the soil for many years.

Vegetative

Reproduction from root pieces and severed crown pieces are the secondary means of reproduction.

Competition

Bladder campion prefers undisturbed areas and proliferates in perennial crops. Cultivate badly infested perennial crops, put into annual crops and till well for two or more seasons. Bladder campion does not compete well in healthy, cultivated crop stands.

Management Strategy

Prevention of seed production is the key to limiting the spread of bladder campion. Starvation through repeated tillage helps control established weed patches.

Tillage

Intensive cultivation or mowing for two seasons is required to starve out bladder campion.

Pre-seeding tillage - Control weed seedlings that germinate early in the spring with a shallow tillage before or at seeding time.

Fall tillage - Deep cultivation with a disc will sever the weed roots below the crown and leave the plant in a weakened state for winter.

Rotation

Crop rotation will only suppress bladder campion, not eliminate it. Do not put infested fields into perennial forage production, because this weed will proliferate if undisturbed. Cereals offer good competition and allow for post-seeding tillage. Summer fallow is an effective control for this weed, but mowing rather than tillage will lessen the risk of soil erosion. Annual crops cut for greenfeed allow for deep cultivation in spring and fall or can be cut before the main flush of weed seeds are set.

Seeding

Shallow tillage to destroy emerging shoots and seedlings should be done prior to or at seeding. Seed cereals 7.5 cm deep if post-seeding tillage is required. Do not seed other crops on infested land.

Mowing

Repeated mowing of small patches of bladder campion in waste-lands and perennial crops is laborious but effective.

CANADA THISTLE

Cirsium arvense

Courtesy of DowElanco

Life Cycle

A perennial, reproducing mainly by horizontal roots and by seed.

Emergence

Shoots from horizontal roots appear on the soil surface around mid-April and continue to emerge throughout the summer. Seeds germinate from late May through to fall.

Flowers

Flowers appear in mid-June and continue into September.

Reproduction

Seed

Seed can be viable eight to ten days after flowering. Fresh seed will germinate readily or go dormant for up to three years. Although Canada thistle is a prolific seed producer, control should be aimed mainly at vegetative reproduction.

Vegetative

New roots, which develop from old roots, continually replace weak or dead roots. Horizontal growth is rapid and roots can regenerate from small pieces. Begin control measures to starve roots when flowering begins in early to mid-June, at the low point of food reserves in the roots.

Competition

Canada thistle is extremely competitive. However, established perennial forages compete well, provided they are cut twice each year. The following table shows estimated yield losses of barley and canola caused by Canada thistle. Actual yield losses may vary from year to year depending on climatic conditions.

Canada thistle per ft ²	percentage yield loss	
	Barley	Canola
0.5	18	5
1	25	16
2	35	30
3	43	41
4	50	50
5	56	58

Management Strategy

Root starvation is the key to controlling Canada thistle. Control of seed production is secondary.

Control Mechanisms

Tillage

Summer fallow - The principles of root starvation apply in controlling Canada thistle in summer fallow. Control measures must continue when the land is cropped.

Pre-seeding tillage - Tillage prior to or at seeding will cut emerging thistle shoots and set them back slightly.

Post-seeding tillage - Control of Canada thistle is not feasible by this means.

Fall tillage - Fall tillage is important because food reserves will increase otherwise. Begin tillage of annual crops as soon as possible after harvest. If moisture conditions allow, repeat tillage when shoots reach 10 cm until freeze-up.

Rotation

Oilseeds and specialty crops generally do not compete well on land infested with Canada thistle. Fall rye and winter wheat offer fall competition and weaken late fall thistle infestations. Annual cereals can be used in rotation if they are planted early and if land is tilled in the fall after cereals are removed.

Seeding

Early seeding allows cereals to compete better with Canada thistle. Seed perennial crops, such as alfalfa and crested wheatgrass, slightly heavier than normal and into moist soils to encourage strong emergence.

Mowing

Mowing is effective on summer fallow and eliminates the risk of erosion from tillage. If done every three to four weeks from June through September, the weeds will become weakened. Thistles die out eventually in perennial forages that are cut twice or more each year.

Biological control

One insect, the weevil *Ceuthorhynchus litura*, has been established on Canada thistle at one site in Alberta. The larvae bore into the stems of the thistle and weaken the plants, sometimes killing them. However, the thistle plants seems to be able to compensate for this damage. *C. litura* increases and spreads very slowly from its release point and does not seem promising as a biological control agent.

A beetle, *Lema cyanella*, which feeds on the leaves of Canada thistle, has been approved for release in Canada. It has not yet been released in Alberta because of problems in rearing enough beetles for release, but further attempts will be made. Other insects are being studied for possible biological control of Canada thistle.

CHICKWEED

Stellaria media

Courtesy of DowElanco

Life Cycle

An annual or winter annual that reproduces by seed and stems roots at the nodes. The winter annual form occurs only in mild climates.

Emergence

Two main flushes of emergence occur, early spring and late fall. Sporadic emergence occurs through the summer.

Flowers

Flowers appear four to five weeks after emergence. Flowers open only for one day.

Reproduction

Seeds

Seeds of chickweed are viable as soon as they are shed. Buried seeds require light before germination can occur. Most seeds germinate within three years after being shed, but deeply buried seed can survive for up to 60 years.

Vegetative

Chickweed will root at the nodes of prostrate stems in moist, loose soil.

Competition

Chickweed is not a strong competitor in established crops and

grows only in bare patches, but seedling crops can be smothered when chickweed forms a mat and covers them.

Chickweed is a problem because it remains green and can wrap around moving parts of harvest equipment. If weather is cool and wet, chickweed will grow on swaths and delay drying time and make pick-up difficult.

Management Strategy

The main control strategies are prevention of seed production and prevention of re-establishment after cultivation. Special attention must be given to prevent growth and seed production in late fall.

Control Mechanisms

Tillage

Summer fallow - Summer fallow encourages the growth of chickweed because there is no crop cover to provide competition. Till immediately following the first emergence of chickweed and continue to till with each subsequent flush. Tillage must bury the chickweed or it will easily re-establish itself by rooting at the nodes on the stems.

Pre-seeding tillage - Early shallow tillage encourages germination of weed seeds. When the seedlings emerge the land should be tilled again and then seeded. Seeding will be delayed by approximately 10 days and some surface moisture will be lost.

Post-seeding tillage - Post-seeding tillage is not an effective control for chickweed since chickweed plants are dragged and not buried and easily re-roots from stem nodes.

Fall tillage - Fall tillage is important to control chickweed that would otherwise set seed or overwinter. The best control will result when weeds are buried and not allowed to re-root.

Rotation

Strong stands of perennial crops are beneficial in suppressing chickweed. Annual crops, once established, can also effectively suppress this weed. Summer fallowing must be thorough in spring and late fall to keep chickweed growth in check.

Seeding

Increase seeding rates for chickweed infested land by up to 25 per cent to encourage crop competition. Seeding may be delayed while waiting for the early spring emergence of chickweed.

Mowing

Close mowing will help to reduce seed set of chickweed; however, many prostrate plants will not be cut.

CLEAVERS

Galium aparine

From Weeds of Wyoming

Life Cycle

An annual that reproduces by seed.

Emergence

The main flush of seedlings is in midspring with fewer seeds germinating throughout the summer.

Flowers

Cleavers flowers from June through August and seed is produced from August to freeze-up.

Reproduction

Cleavers produces large quantities of seed. They are difficult to separate from canola seed owing to their similar shape and size. Cleavers seed becomes dormant in dry soil and can remain viable for one to three years.

Competition

Cleavers can be very competitive because it clings to crop plants when growing towards light. The trailing plants can become tangled in moving parts of harvest equipment. Seed quality suffers when canola seed is infested with cleavers seed. Established forages compete well with cleavers.

Management Strategy

Prevent seed production, especially in canola fields, and sow clean seed.

Control Mechanisms

Tillage

Summer fallow - The number of cleavers seed can be reduced by summer fallowing. Till weed flushes to shallow depths to prevent seed production. Plants can re-root in moist soil, so tillage is most effective under warm dry conditions.

Pre-seeding tillage - An early shallow tillage encourages germination of cleavers seeds. A second tillage, immediately before or at seeding destroys these seedlings. Seeding may be delayed, however. If delayed seeding is not possible, sow the crop early so that it gains a competitive advantage over cleavers.

Post-seeding tillage - If pre-seeding tillage is performed then post-seeding tillage should not be necessary. Crops that are seeded early may not benefit from post-seeding tillage because crop growth may be too advanced before weed emergence is complete.

Fall tillage - Fall tillage will encourage cleavers seeds to germinate and the seedlings will be killed by frost.

Rotation

Rotations that include summer fallow, cereals, and annual and perennial forages should help minimize cleavers populations. Winter annual cereals are especially effective. Do not grow canola on land infested with cleavers because cleaning cleavers seed from the crop is very difficult.

Seeding

Spring seeding of land infested with cleavers should be either very early or delayed until after weed seedlings emerge.

Mowing

Because of the prostrate growth form of cleavers, mowing is not effective.

CORN SPURRY

Spergula arvensis

Courtesy of DowElanco

Life Cycle

An annual that spreads by seed.

Emergence

Main seedling emergence is in mid-spring with sporadic emergence throughout the summer.

Flowers

Flowers appear mainly from July to September.

Reproduction

Seeds are produced from late July through September. Seeds remain viable for more than three years. Clover and grass seed may contain impurities of corn spurry seed.

Competition

Corn spurry is an aggressive competitor. It grows mainly on light, acid soils. Growth is very rapid and can smother emerging crops.

Management Strategy

Prevent seed production and encourage germination of existing seeds.

Control Mechanisms

Tillage

Summer fallow - Summer fallow badly infested land and start with a shallow fall cultivation to encourage germination. In the next season each successive tillage should be deeper to bring seeds to the surface to germinate. This system of control will be effective provided there is moisture for seed germination.

Pre-seeding tillage - A shallow tillage should be made at or prior to seeding.

Post-seeding tillage - Post-emergent harrowing is effective in cereals if corn spurry emerges with the crop.

Fall tillage - Harrowing or shallow cultivation in the fall will encourage seeds to germinate and expose seedlings to frost.

Rotation

Summer fallow land infested with corn spurry before a crop is seeded. This is especially important before seeding perennial forages because forage seedlings can not compete with corn spurry. Once established, forages compete well with corn spurry.

Seeding

Clean seed, especially legumes and grasses, is a fundamental requirement for preventing the spread of corn spurry. If cereals are harrowed after emergence, seed deeper than normal to minimize crop injury.

Mowing

Mowing will stunt corn spurry growth, but the shoots that are cut will quickly re-grow.

COW COCKLE

Saponaria vaccaria

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed. Cow cockle appears to be a problem only in the Brown and Dark Brown soil zones.

Emergence

Main seedling emergence is in early spring.

Flowers

Cow cockle flowers in late June and July.

Reproduction

Seed is produced in late July and August. Most seed germinates the following year and the remainder germinates the second year. All plant parts are poisonous, especially the seeds.

Competition

Cow cockle does not compete with established perennials but does compete with annual crops.

Management Strategy

Prevention of seed production is crucial in the control of cow cockle.

Control Mechanisms

Tillage

Summer fallow - Clean summer fallow is an effective control for this weed because the seeds are only viable for a few years. The first tillage should be made after the main flush of weeds.

Pre-seeding tillage - Early, shallow tillage encourages cow cockle seeds to germinate. When the weed seedlings emerge, till and seed. Seeding will be delayed about 10 days and some surface moisture will be lost.

Post-seeding tillage - If seeding is delayed, post-seeding tillage should not be required. Post-emergent harrowing can be done on cereals if necessary.

Fall tillage - Fall tillage will destroy existing cow cockle seedlings and mature plants that have escaped.

Rotation

Perennial forages grown for three to four years will greatly reduce cow cockle populations. Summer fallow is also effective in controlling this weed. Seed annual crops up to 25 per cent heavier than normal to encourage a strong crop stand. Do not plant flax on infested land.

Seeding

Delayed seeding allows for spring tillage to control the main flush of cow cockle. Annual crops may be seeded heavier than normal to ensure strong stands.

Mowing

Mowing of weedy patches before seed set limits cow cockle populations.

DANDELION

Taraxacum officinale

Courtesy of DowElanco

Life Cycle

A perennial, reproducing mainly by seed. New plants can develop from severed root pieces.

Emergence

Dandelion flowers appear throughout the growing season, but they are most abundant in spring.

Reproduction

Seeds are viable and ready for dispersal within two weeks of flowering. Dandelion seeds can survive for more than three years in the soil.

Competition

Dandelions are mainly a problem in weak forage stands. Fertilization or renovation of the stand will help decrease dandelion populations. Dandelions do not compete well in healthy, strong perennial crops. Dandelions are not usually a problem in annual crops that undergo tillage.

Management Strategy

Prevention of seed production is not practical. Dandelions

grow in many non-crop situations and seed can travel great distances. Instead, perennial forages should be managed to prevent dandelions from becoming established.

Control Mechanisms

Tillage

Summer fallow - Summer fallow is not necessary to control dandelions. Spring and fall tillage destroys the roots beneath the crowns.

Pre-seeding tillage - Deep tillage to 10 cm will sever established dandelion taproots and destroy seedlings. A heavy duty cultivator followed by a rod weeder works best.

Post-seeding tillage - Tillage to control established plants after seeding is not effective. However, it is effective for control of dandelion seedlings in cereals. Should dandelion seedlings be a problem, tillage can be done before or after crop emergence.

Fall tillage - Deep tillage to 10 cm will sever established dandelion taproots and destroy seedlings. A heavy duty cultivator followed by a rod weeder generally works well.

Rotation

Fertilize and re-seed weak forage stands. If this is not successful, work the forage crop down and seed an annual crop. Healthy perennial forages in the rotation for three to five years will reduce dandelion seed quantities. Most annual crops will compete well, as long as the crop stand is heavy and vigorous.

Seeding

Seeding should proceed as normal with heavy (+25%) seeding rates for perennial crops. Cereals that require post-seeding tillage should be seeded deeper and heavier than normal.

Mowing

Mowing is not an effective control for dandelions, owing to the low growth form of this weed.

FIELD BINDWEED

Convolvulus arvensis

Courtesy of DowElanco

Life Cycle

A perennial that reproduces by seeds and root buds.

Emergence

Seeds of field bindweed germinate throughout the growing season, with peak germination in late spring. Shoot growth begins when day temperatures are near 14°C and night temperatures are at least 2°C.

Flowers

Field bindweed flowers from early July until freeze-up.

Reproduction

Seed

Seed set is enhanced by dry, sunny, weather. Seeds have a hard seed coat and can survive in the soil for 20 to 30 years. Seed may not be produced by plants growing in frequently cultivated soils.

Vegetative

Seedlings produce a taproot, which quickly develops lateral roots. Rhizomes develop from root buds, and shoots then

develop from rhizomes. Each piece of rhizome is capable of starting a new plant.

Competition

Field bindweed competes poorly for light but can compete for soil moisture because of its extensive root system. This weed can cause severe yield reductions and, once established, can cause crop lodging and can also interfere with harvest.

Fall rye, winter wheat, alfalfa and crested wheatgrass compete well with field bindweed.

Management Strategy

Pay special attention to preventive control measures because this is a persistent weed. Prevention of seed production and root starvation are the main control strategies.

Control Mechanisms

Tillage

Summer fallow - A tillage operation every three to four weeks from June through September is the only non-chemical solution for controlling field bindweed. This must be done for two seasons. Use a combination of cultivation, crop rotation and herbicides to control infestations of field bindweed.

Pre-seeding tillage - Till fairly deep (10 cm) to cut the roots and delay shoot growth so that the crop seedlings have a competitive advantage.

Post-seeding tillage - Post-seeding tillage is only effective for controlling field bindweed seedlings in cereal crops.

Fall tillage - Food reserves in field bindweed roots are at a peak in October. Cultivation at this time is risky because the root pieces have a greater chance of survival when stored food levels are high. If necessary, use herbicides at this time to weakening the plant and decrease its winter survival.

Rotations

Rotations should include competitive plants such as fall rye, winter wheat, alfalfa and crested wheatgrass. Do not use forages for pasture when the weed is confined to isolated patches because grazing causes the weed to spread. Seeds of field bindweed can be spread in the feces of livestock. Reseed or work down perennial crops when the stand becomes weak.

Seeding

Seeding as usual unless post-seeding tillage is required for cereal crops.

Mowing

Seed production of field bindweed will be minimized when this weed is cut with perennial crops. Prostrate plants generally escape cutting.

FLIXWEED

Descurainia sophia

Courtesy of DowElanco

Life Cycle

Annual or winter annual that reproduces by seed.

Emergence

Seedlings emerge mainly in the fall and early spring.

Flowers

Overwintered rosettes begin to flower near the end of May. Flixweed that emerges in spring starts to flower in mid-June. Both growth forms continue to flower through the summer.

Reproduction

Flixweed shatters easily and produces large quantities of seed. Seeds can survive in the soil for more than three years.

Competition

Overwintered rosettes are strong competitors because they grow rapidly in the spring and use valuable spring moisture before fields can be worked. Spring-emerging flixweed seedlings do not compete as well, especially in heavy crop stands. Flixweed can be a severe problem in perennial forage crops grown for seed.

Management Strategy

The winter annual adaptation is the strongest survival mechanism of flixweed. Crucial steps to control flixweed include prevention of seed production and control of fall rosettes.

Control Mechanisms

Tillage

Summer fallow - Summer fallow alone will not control flixweed because seed remains viable in the soil for many years. Infested land need not be in summer fallow as long as spring and fall tillage is performed and effectively kills the weeds.

Pre-seeding tillage - Tillage before seeding is crucial to control flixweed. Regardless of the crop, shallow tillage before seeding is necessary to destroy any existing seedlings or rosettes.

Post-seeding tillage - Post-seeding tillage should not be necessary if pre-seeding tillage is performed.

Fall tillage - Late fall tillage will control flixweed rosettes that would otherwise overwinter. Take care to leave enough crop residues to protect the land against erosion.

Rotation

Flixweed in established winter annual crops cannot be controlled without chemicals. However, any heavily seeded, fertilized annual or perennial crop should compete well against flixweed.

Seeding

Seed crops slightly heavier than normal to encourage competition. Cereals that may require harrowing after emergence should be seeded deeper than normal (7.5 cm).

Mowing

In the year that perennial crops are established, mowing is effective to prevent flixweed seed production, although low growing plants may be missed.

GREEN FOXTAIL (WILD MILLET)

Setaria viridis

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed.

Emergence

The main seedling emergence occurs in late spring as soil temperatures increase and coincides with crop emergence. Flushes occur in the summer especially after periods of high rainfall.

Flowers

The main flush of weeds begins to flower in mid-July; green foxtail that emerges later, flowers through the summer.

Reproduction

The first green foxtail seeds mature two weeks after flowering begins. Dormancy lasts for 4-10 weeks, or longer if it is dry. Shallowly buried green foxtail seeds remain viable in the soil for up to three years. Survival of seeds increases with depth of burial. Green foxtail plants are prolific seed producers. Seed production is reduced if plants grow under heavy crop canopies.

Competition

Individual green foxtail plants are not strongly competitive. Under certain conditions, however, large populations can substantially reduce crop yields. Green foxtail is most competitive under high light and warm temperature conditions. Green foxtail that emerges earlier in the season is generally more competitive than later emerging plants.

High populations of this weed can be attributed to shallow early spring tillage, delayed seeding for wild oats control, and broadcasting of fertilizers. Because green foxtail competes strongly for nitrogen, deep banding of nitrogen fertilizer will limit its availability. Barley and oats compete better with green foxtail than wheat does. However, green foxtail still represents the largest portion of dockage in all of these crops.

Perennial forages compete well and should be grown for three or four years.

Management Strategy

Prevention of seed production is the key to controlling green foxtail. Make a special effort to keep this weed from spreading to uninfested land.

Control Mechanisms

Tillage

Summer fallow - A season of summer fallow will greatly reduce populations of green foxtail. The first deep tillage will bring buried seeds to the surface to promote germination. Subsequent tillage should be shallow so that seeds remain near the surface for germination.

Pre-seeding tillage - Shallow tillage encourages seeds near the soil surface to germinate. Spring cultivation and seeding should be early, so that the crop can gain a competitive advantage over later-emerging green foxtail.

Post-seeding tillage - Post-seeding tillage will probably be necessary in cereals seeded in the spring because soil disturbance at seeding encourages green foxtail emergence.

Fall tillage - In dry years, shallow fall tillage buries green foxtail seeds and encourages germination in the following spring. In damp cool fall weather, green foxtail seeds should be left on the soil surface so that they can lose their dormancy and germinate. Green foxtail seedlings cannot survive the winter.

Rotation

Summer fallow reduces green foxtail numbers. Three to four years of perennial forage crops will also decrease green foxtail populations because the seeds are only viable for about three years. Cut badly infested crops for greenfeed before the green foxtail seeds shatter. Cereals and oilseeds are the most difficult crops in which to reduce green foxtail populations. If these crops are seeded earlier and heavier than normal, they should prevent further infestations of green foxtail.

Seeding

Seed perennial crops after the main emergence of green foxtail following shallow tillage. Seed cereals early to increase competitiveness. If cereals cannot be seeded early, seed them deeper and heavier than normal so that post-seeding tillage can be done. Seed oilseeds earlier and slightly heavier than normal to encourage a competitive crop stand.

Mowing

Mowing of perennial forages is effective if done before green foxtail produces seed. However, seeds are usually viable in mid-June before hay is ready to be cut.

HEMP NETTLE

Galeopsis tetrahit

Courtesy of DowElanco

Life Cycle

An annual reproducing by seed.

Emergence

Hemp nettle emerges mainly in mid-spring with scattered emergence through the summer.

Flowers

Hemp nettle flowers from July through September

Reproduction

Seeds of hemp nettle are covered by a hard seed coat that prevents germination for up to three years. Warm soil temperatures encourage seed germination. Large quantities of seed are produced by each plant starting in early August. Plants cut near maturity contain enough moisture and nutrients to ripen the seeds.

Competition

Hemp nettle competes vigorously with crop plants for space and nitrogen. The weed often germinates at the same time as annual crops and competes early in the season.

Management Strategy

It is difficult to manipulate the germination of existing weed seeds, so the best control strategy is reduction of seed production.

Control Mechanisms

Tillage

Summer fallow - Firm, moist summer fallow that is cultivated to a shallow depth provides conditions for dormant seeds to germinate. Cultivate after the seedlings emerge.

Pre-seeding tillage - A combination of tillage and seeding after weed emergence will destroy the majority of weed seedlings. The crop then has the competitive advantage over the weeds.

Post-seeding tillage - Post-seeding tillage is risky and should be done only when other control measures are not feasible.

Fall tillage - Early fall tillage destroys hemp nettle plants and encourages germination of seeds in the soil.

Rotation

Grow perennial forages on badly infested land for at least three years. Cut the forage each year before weeds produce seed. Management to improve forage growth should inhibit hemp nettle. Annual crops do not compete well with hemp nettle. If cereals are used in the rotation then post-seeding tillage can be done if necessary. Summer fallow works well in the crop rotation; seeds germinate and emerge only to be destroyed by cultivation.

Seeding

Seed annual crops early in the spring when possible, so the crop will emerge before hemp nettles. Seeding of cereal crops at regular times can be followed by post-seeding tillage, if the cereals are seeded deep. If seeding is delayed, the seeding operation will destroy hemp nettle seedlings. Plant an early maturing crop. Seed perennial crops after the main emergence of hemp nettle so that pre-seeding tillage destroys existing seedlings.

Mowing

Close mowing of perennial crops prior to production of weed seeds decreases hemp nettle populations.

KOCHIA

Kochia scoparia

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seeds.

Emergence

Most kochia seeds germinate before mid-May.

Flowers

Kochia flowers from July through September.

Reproduction

Kochia can be a prolific seed producer, but its seed production is usually disrupted when crops are cut or harvested. Kochia seeds do not remain alive in the soil for more than a year.

Competition

Kochia is a strong competitor, especially on cultivated land that is dry or saline. It tolerates salinity levels too high to support most crop growth and can reduce salinity levels of soils. Consequently, kochia may be beneficial. Kochia also helps to stabilize the soil and is palatable to livestock.

Management Strategy

Prevention of seed production for a year eliminates kochia infestations.

Control Mechanisms

Tillage

Summer fallow - One year of summer fallow reduces kochia populations because no new seed is produced. The first tillage should be in late May after kochia emergence.

Pre-seeding tillage - The seeding operation generally destroys most kochia seedlings.

Post-seeding tillage - Post-seeding tillage should not be necessary because most kochia seeds germinate prior to seeding and are destroyed at seeding.

Fall tillage - Fall tillage should not be required specifically for kochia unless plants are setting seed.

Rotation

Clean summer fallow limits the spread of kochia. Infested land can be seeded to perennial forages that are salt tolerant and mowed before kochia set seed. Strong annual crops should compete with kochia as long as the land is not too saline.

Seeding

Seeding may need to be delayed slightly until the main flush of kochia is complete.

Mowing

If possible, cut perennials before kochia produces seed. Harvesting of annual crops will usually disrupt kochia seed production.

LAMB'S-QUARTERS

Chenopodium album

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seeds.

Emergence

Lamb's-quarters emerge mainly in early spring with sporadic germination through the summer.

Flowers

This weed flowers from June through September.

Reproduction

Seeds ripen from August onwards. Lamb's-quarter seeds are viable in the soil for up to 20 years. Dormant seeds are produced when days are long. Non-dormant seeds are produced under short days. Dormancy is broken when weed seeds are brought to the soil surface.

Competition

Lamb's-quarters competes with crops to some extent, but is not aggressive. This weed robs crops of nutrients and moisture.

Management Strategy

Prevention of seed production is the way to control lamb's-quarters.

Control Mechanism

Tillage

Summer fallow - Badly infested land can be summer fallowed every three years to suppress lamb's-quarters populations.

Pre-seeding tillage - If moisture allows, use pre-seeding tillage to encourage germination by bringing seeds to the soil surface. Seeding may need to be delayed slightly until the main weed flush has emerged.

Post-seeding tillage - If pre-seeding tillage and delayed seeding are used, post-seeding tillage should not be necessary. However, if the weeds are a problem after cereal emergence, they can be destroyed by harrowing.

Fall tillage - Fall tillage encourages seedling emergence and destroys weeds that may otherwise produce seed.

Rotation

Using summer fallow every three to four years will help minimize lamb's-quarters infestations.

Perennial crops maintained for three or four years should reduce weed seed production. Heavy plant canopies reduce light levels and inhibit germination of lamb's-quarters seeds.

Annual crops that are used in a rotation to suppress lamb's-quarters should be seeded after the main flush of weeds has been destroyed. The crop then has a competitive advantage, and the crop canopy will inhibit germination of the remaining lamb's-quarters.

Seeding

All seed should be cleaned because lamb's-quarter seed is a common impurity in forage and cereal seed.

Delay seeding of spring crops until the majority of lamb's-quarters has emerged so that weed seedlings are destroyed during the seeding operation.

Mowing

Close mowing will eliminate lamb's-quarters in perennial crops, because this weed cannot withstand cutting. Mowing of headlands will prevent seed production and prevent the spread of lamb's-quarters into fields.

LEAFY SPURGE

Euphorbia esula

Courtesy of OMAF

Life Cycle

Leafy spurge is a herbaceous deep-rooted perennial weed that reproduces from seed and from numerous vegetative buds on its extensive, persistent vertical and horizontal root system.

Distribution

Leafy spurge is present throughout Alberta. Infestations are limited to waste areas, river bottoms and flood plains. Heavy infestations in cultivated fields are rare.

Germination

Temperature is probably the most important environmental factor affecting leafy spurge seed germination. Tests have shown that alternating temperatures of 20° and 30° C produced a germination of 84 per cent while germination at 18° to 20° C was only 8 per cent.

Leafy spurge germination in the field can occur throughout the growing season whenever adequate moisture is available; however, early spring is most favorable for germination.

Emergence and Growth

Leafy spurge seedlings can emerge through several centimetres of soil even though the seed is not large. Seedling emergence may occur from a depth of up to 15 cm. Seedling development is rapid after emergence.

The rate of growth and spread of leafy spurge from seedling varies with competition. One study showed that plants from seed produced only a single stem in the seedling year when grown with or without competition. No plant grown with competition produced more than the original shoot during the second growing season. However, plants from seed grown without competition averaged 170 shoots per plant and spread a distance of 134 cm from the point of the original shoot by the end of the second growing season. Another study reported that seven seedlings only occupied 0.2 m² after the first growing season but had increased to occupy 44 m² after five years.

Flowers

Within one week of emergence, flowers start to develop and can bloom as early as mid-May. Flowering generally ceases between the end of June and mid-July. Development and maturation of seed extends for some 30 days beyond the appearance of the last flower. Flower production and seed development are continuous from mid-May to mid-August.

Reproduction

Seed

Leafy spurge pollen is sticky, so most of the pollination is done by insects. The pollen is most viable 24 hours after emergence of the male flower. The general mechanism of flower development minimizes self-pollination because the female develops before the male flowers.

The peak period for seed maturity is mid to late July. Average seed production of leafy spurge is 2,500 seeds/m² with a range from 790 to 8,020 seeds/m².

Fresh leafy spurge seeds have a viability of 60 to 80 per cent. Viability, however, is dependent mostly on the depth of burial in the soil. A seed source was initially 87 per cent viable, but the viability after three years of burial was 12, 18, 43 and 64 per cent at depths of 2.5, 5, 10 and 20 cm, respectively. Thus, seed near the soil surface lost viability most rapidly. There is around 13 per cent annual loss of leafy spurge viability in undisturbed pastures.

Seeds float on the water surface. This ability appears to be an advantage for leafy spurge establishment in areas that flood occasionally. Ditch, stream and river banks are often the location for new leafy spurge infestations.

Dormancy of leafy spurge permits germination for at least five years following maturity and up to eight years after the seed is deposited.

Vegetative

Vegetative reproduction of leafy spurge is by buds that survive overwinter under the soil surface. Crown buds and root buds produce stems.

The crown of leafy spurge develops at the base of the stem and consists of buds that produce new stems at the same location every year. Buds that do not sprout in the spring apparently slough off during the season and are replaced by new buds. The new buds reach full size by late summer. Some buds grow into shoots that emerge during the late summer and fall.

The root system of leafy spurge is the primary contributor to the persistence of the weed. The root system is deep and spreading. It can produce shoot buds at almost any point along any root segment. The upper portion of the plant can be injured or killed by tillage or herbicide treatment, but the remaining root system, either below the treatment or from detached root segments, can develop adventitious buds that will send up new shoots from a depth of 30 cm or more.

Competition

Leafy spurge can survive in most environments. It can even withstand floods for 4 1/2 months or more if the depth of water does not prevent emergence of the shoots above the surface. However, heavy competition reduces leafy spurge growth. An early emerging crop, such as crested wheatgrass and smooth brome grass that uses the available moisture early in the season, may limit the spread and establishment of new leafy spurge infestations.

Some species of plants produce chemicals that inhibit the growth of other species of plants. This is called allelopathy. Allelopathy by leafy spurge on other plants is indicated by the small number of forbs in leafy spurge patches even when bare ground is visible between shoots. Several reports provide indirect evidence that leafy spurge may be allelopathic with other plants under laboratory conditions. However, verification of allelopathy of leafy spurge still requires isolation of an active compound(s) from plants and evidence that the chemical is phytotoxic in the soil.

Management Strategy

- Prevent establishment where applicable.
- Prevent seed production.
- On established sites, exhaust root reserves.

Control Mechanisms

Tillage

Tillage from immediately after small grain harvest until freeze-up, followed with a season of intensive tillage the next year, can kill a high percentage of leafy spurge.

A duckfoot cultivator or blade-type implement is the best equipment for cutting the heavy tough roots of leafy spurge. The wide sweeps or blades should overlap 7.5 to 10 cm, be kept sharp and adjusted so they are flat when in the soil and operating at a depth of 10 to 13 cm.

New shoots require seven to 10 days to emerge after the roots have been cut. Another seven to 10 days are required before there are

enough leaves to produce more food than is needed for growth. Therefore, the root reserves are being used for plant growth for 14 to 20 days after each cultivation. The most practical interval of tillage is every two weeks during good growing conditions and every three weeks during dry, hot weather when plants are growing less rapidly. This generally means that tillage should be done at two-week intervals during late May, June and July and at three-week intervals during August, September and October.

Competitive Crop

Few, if any, crops are competitive enough to eliminate leafy spurge. However, a crop that has one or more of the following characteristics may help to control or reduce the growth of leafy spurge: (a) early spring growth (winter crops), (b) late seeding date to allow a tillage operation before seeding, and (c) dense foliage.

Mowing

Mowing to prevent seed production and starves the underground parts. To prevent seed production, mow before viable seeds are formed. To deplete root reserves, mow when the underground root reserves are low, which occurs between full leaf development and the time when flowers appear during late spring. Never allow the plant to replenish its underground food supply.

Grazing

Sheep readily graze leafy spurge once they are accustomed to it. Sheep require two to three weeks to get accustomed to the weed. Grazing sheep continuously on leafy spurge prevents the weed from spreading and prevents seed production. Leafy spurge must be grazed rather intensively for several years to reduce density. Using sheep to graze leafy spurge is a practical method of eliminating leafy spurge in many areas where other means are not feasible. Also, it provides an income from forage that may not be productive otherwise.

Biological control

Two spurge beetles (*Aphthona nigriscutis* and *Aphthona flava*) are reducing leafy spurge densities in Western Canada. The larvae feed on the leafy spurge roots and the plant vigor is reduced. Refer to the section on biological control for more details.

Chemical

Several herbicides control leafy spurge. The most effective herbicide is Tordon (picloram). Others include 2,4-D, Dicamba or a combination of both. Chemical selection must be based on the nature of the infestation and environmental concerns. Refer to *Crop Protection with Chemicals*, Alberta Agriculture, Food and Rural Development, Agdex 606-1 for details on chemical selection.

Multi-technique Approach

Like most perennial weeds, a combination of methods are needed to control leafy spurge. Long-term efforts will be required before this weed can be brought under control or eliminated.

NARROW-LEAVED HAWK'S-BEARD

Crepis tectorum

Courtesy of Agriculture Canada

Life Cycle

An annual or winter annual that reproduces by seeds.

Emergence

Main flushes emerge from mid-May to mid-June and from early August to mid-September. The first flush develops as annuals and the second develops as winter annuals. Sporadic emergence occurs at other times.

Flowers

Annuals flower from early July through August. Winter annuals flower the year after emergence between mid-June and mid-July.

Reproduction

Seeds of winter annuals are set from mid-July to mid-August. Seeds from annuals mature from early August through fall. Seeds exhibit little or no dormancy, losing their ability to germinate after about five years.

Competition

Narrow-leaved hawk's-beard is a serious weed of perennial

forages. The winter annual form competes with established forages; the annual form competes with seedling forages, special crops, cereals and oilseeds. The most serious infestations of this weed occur in weak crop stands.

Management Strategy

Prevent seed production and encourage strong crop stands.

Control Mechanisms

Tillage

Summer fallow - Summer fallow reduces populations of narrow-leaved hawk's-beard. However, plants can easily re-root after tillage, especially in wet conditions. Consequently, tillage should be done during hot, dry weather. Perform tillage after the main flushes of annuals appear and in the fall to destroy rosettes of winter annual.

Pre-seeding tillage - Early, thorough spring tillage destroys weeds that have overwintered. Annual crops can then be seeded. Do not seed perennial crops until the first flush of seedlings has been destroyed by cultivation.

Fall tillage - Cultivate thoroughly after weed emergence is complete in the fall, usually around mid-September. If possible, conditions should be dry so that the rosettes do not re-root.

Rotation

Maintain strong stands of perennial crops for three to four years to discourage weed growth. If perennial crops become infested with narrow-leaved hawk's-beard, work the stand under and summer fallow until the following year.

Annual crops in the rotation should be well-fertilized and seeded slightly heavier than normal to encourage competition against spring weeds.

Summer fallow can be an effective control for narrow-leaved hawk's-beard. Perform a shallow tillage after emergence of weeds in the spring and fall and as required during the season.

Seeding

Seed annual crops at a heavier than normal rate after the spring flush of narrow-leaved hawk's-beard. Seed perennial crops after weeds have been destroyed by tillage in the spring. Seed fall crops after the fall flush of weed seedlings has been tilled.

Mowing

Mow narrow-leaved hawk's-beard in perennial crops prior to weed seed production. This is especially important in the year that perennial crops are established.

NIGHT-FLOWERING CATCHFLY

Silene noctiflora

Courtesy of DowElanco

Life Cycle

Annual or winter annual that reproduces by seed.

Emergence

There is no definite period of germination but most emergence is from mid-April to mid-July. Sporadic germination occurs through to fall.

Flowers

This weed flowers from mid-June through September. Mature seeds are produced about a month after the first flowers appear.

Reproduction

This weed is a heavy seed producer. The seed is highly viable. Immature seed from unopened capsules can germinate. The weed seed is easily spread with alsike clover because the seeds

are the same shape and size. A short post-harvest dormancy may exist. Seed can remain viable for more than three years in the soil.

Competition

Night-flowering catchfly, especially the winter annual form, is a strong competitor in moist areas. Established forages compete well and should be maintained for at least three years to deplete reserves of weed seeds in the soil.

Management Strategy

Control the winter annual form in the first season and sow clean seed.

Control Mechanisms

Tillage

Summer fallow - Reduce heavy populations of night-flowering catchfly with summer fallow.

Pre-seeding tillage - It is difficult to know when to use tillage to control night-flowering catchfly seedlings because of the wide germination span. However, early spring tillage will kill any overwintered seedlings and the early germinating annuals.

Post-seeding tillage - Do post-seeding tillage of cereals only when other control measures are not feasible.

Fall Tillage - Late fall tillage will control rosettes of the winter annual form that would otherwise overwinter.

Rotation

Rotations of at least three years in perennial forages will reduce seed numbers in the soil. Summer fallow will also help deplete seed reserves.

Seeding

Spring tillage at or before seeding destroys weed seedlings and allows the crop to gain a competitive advantage over the weeds.

Mowing

Mow before seed production to control night-flowering catchfly, especially in the year that forages are established.

QUACKGRASS

Agronpyron repens

Courtesy of DowElanco

Life Cycle

A persistent perennial grass spread by rhizomes and seeds.

Distribution

Quackgrass is present throughout Alberta, but it is more prevalent in cooler, moister areas than in warmer, drier parts of the province. The less adapted a weed is to a climatic area, the less the probability of it invading and the easier it is to control established patches.

Percentage of fields containing quackgrass

Agricultural region	per cent
Region I (Lethbridge area)	1
Region II (Calgary area)	6
Region III (Red Deer area)	14
Region IV (Vermilion area)	27
Region V (Barrhead-Edmonton area)	15
Region VI (Peace River area)	22

Germination

Quackgrass seed germinate at temperatures between 5-30°C and does not require an after-ripening period to germinate. It does not require temperature fluctuation to germinate. This temperature response favors germination during most of the growing season with the exception of July and early August when conditions tend to be too dry in most of Alberta.

Emergence and Growth

Seedlings germinate and rhizome buds start growth at soil temperatures greater than 5°C. Soil temperature of 5-15°C favor shoot growth. While growth is stopped completely at 40°C, this condition rarely occurs in Alberta. Recovery of

quackgrass is poor at higher temperatures, so this is a good time for a control operation. The long days of spring favor rhizome development.

Flowers

Flowering and seed production occur in June and early July in grassland and fields with minimum tillage. Seeds ripen by late July or early August. Several tillage operations will delay flowering and seed set by two or three weeks.

Reproduction

Seed

Quackgrass is self sterile. Production of viable seed requires cross pollination from genetically different clones. This is the primary reason why viable seed production is low and spread by seed is minimal. However, forage seed contaminated with even a few quackgrass seeds may not only infest clean land, but may also introduce genetically different clones to areas previously occupied by a single clone and so may make seed production possible.

Buried seed may lie dormant for two to three years and retain its viability for about four years. The prevention of seed production for four to five years may reduce or prevent seedling production but will not eliminate the quackgrass problem.

Vegetative

The creeping underground stem, called a rhizome, is the main method of reproduction. Each bud on this stem is capable of producing a new shoot, if stimulated. Dormant buds can produce new shoots through cultivation and by mowing above-ground parts. Most rhizomes are in the top 10-15 cm of soil. Tillage need not be much deeper than 15 cm to be effective and disrupt all rhizome production.

Facts about quackgrass rhizomes

1. In one year, a plant produced from a single bud can:
 - spread to an area 3 metres in diameter,
 - produce 135 metres of new rhizome,
 - produce 206 aerial shoots.
2. Long days favor rhizome development.
3. High light intensity in open fields favors rhizome development.
4. Shade to less than 3 per cent sunlight completely stops rhizome growth.
5. Soil temperature of 5-15°C favors rhizome growth.
6. Frost only kills rhizomes on the soil surface.

Competition

Quackgrass is a strong competitor with crops for several reasons. First, it can maintain high growth rates in cool weather. Second, quackgrass can tie up a large percentage of N, P, and K from the soil and make them unavailable to the crop. Third, this weed reproduces easily from vegetative plant parts. Furthermore, quackgrass may contain toxins that inhibit growth of crops or other weeds. The allelopathic effect appears to be linked to dead plant parts. It is not clear whether the inhibitor is a product of microbial activity or if it is leached from the quackgrass itself.

Losses from quackgrass in the short-term depend on the crop and the quackgrass density as shown in the following graph. In the long term, quackgrass may limit the type and frequency that a specific crop can be produced economically.

Effect of quackgrass on yield

* Information not available

Sources: J.T. O'Donovan (1987), Monsanto Canada Inc. (1985)

Management Strategy

- Prevent establishment where applicable.
- Exhaust root reserves on established sites.

Control Mechanisms

Tillage

In prairie and parkland regions, intensive tillage can offer a means of control. This practice involves the principle of "shredding" and "dragging out".

"Shredding" causes quackgrass roots to produce underground growth and at the same time prevents this growth from reaching the sunlight and producing leaves. Thus, the buds on the roots use their reserve food material to develop sufficient leaf area for the manufacture of food. The frequent shredding of the roots stimulates a large number of dormant buds to grow, leading to the exhaustion of the food reserves. Shredding can be accomplished with tillage by a

plow, rotovator, or one-way disc. Each tillage operation should be carried out before the quackgrass growth reaches 5 cm. Till infested patches separately from the remainder of the field.

The "dragging-out" method brings intact root stocks to the surface to dry out. This method is more effective under hot, windy, dry conditions. A cultivator with a cable weeder or rod weeder with oscillating harrows behind, "drags out" the root stocks.

Half-way measures of cultural weed control may result in a better stand of quackgrass. Follow-up tillage is required to prevent this weed from re-infesting clean field. Sowing a competitive crop such as fall rye, barley or canola will maintain crop yields in a quackgrass infested field.

Pre-seeding Tillage - Avoid tilling quackgrass infested patches at this time if possible because new plants from underground stem pieces will be impossible to control in the crop.

Inter-row Tillage - Use inter-row tillage when a row crop such as corn is grown.

Fall Tillage - Repeat tillage from harvest to freeze-up to weaken quackgrass stands. Till before the growth reaches 5 cm. In a wet fall, repeated mowing or grazing will create the same results as fall tillage. Fall applications of herbicides may be effective if good growing conditions exist.

Mowing

Mowing can deplete root reserves, but this technique is only practical when soil disturbance is undesirable.

Rotations

Quackgrass is more likely to become established and multiply when land is cleared or broken than when land is left undisturbed. Perennial grass and legume mixes will not compete strongly with this weed. However, quackgrass root systems in mixed stands will develop near the surface and become weak. Quackgrass makes good hay and can be cut with the forage crop to weaken the quackgrass stand. Cut hay before weed seed is produced.

Success of cultural methods can be very dependent on the growing season. In moist summers, shredding the rhizomes is best; in dry summers, dragging them to the surface is most effective. In very wet summers it may be impossible to carry out either procedure. In such years, mow or graze the quackgrass to prevent seed production. Heavy grazing before tillage can improve control. In the year after intensive tillage, till before seeding to reduce infestations by seedling plants and viable rhizome pieces. Intensive post-harvest tillage will further reduce quackgrass re-infestations. Begin tillage after harvest and repeat as required until the soil freezes. Also, the use of strongly competitive crops the following year, such as two-row barley, rapeseed or winter grain, will help suppress quackgrass re-growth.

Herbicides

The use of tillage to control quackgrass often causes serious soil degradation. On the other hand, reducing tillage to minimize this problem will generally result in less quackgrass control. A herbicide treatment can control quackgrass and minimize soil degradation.

Herbicides for quackgrass control fall primarily into two categories:

- Those that can be applied to broad-leaved crops for seasonal grass control (Poast, Fusilade, Assure and other graminicides).
- Those that are non-selective but provide control for more than one season (glyphosate, numerous trade names).

Glyphosate is applied before seeding, after harvest or in summer fallow. The other herbicides are applied in broad-leaved crops such as canola and flax.

Multi-technique Approach

A combination of tillage, herbicide and crop rotation can go a long way to effectively managing quackgrass.

A proven approach to successful control starts with summer fallow. In a summer fallow year, quackgrass can be reduced substantially by an appropriate herbicide treatment followed by tillage. The following table outlines the degree of control and the barley yield in the year following a summer fallow control program at Beaverlodge, Alberta.

Glyphosate applied in June Rate L/ac	+	Frequency and time of tillage after treatments	One year after	
			Quack density shoots/m ²	Barley yield tonnes/ac
0	+	Tillage at 130 days	344	0.307
0	+	Tillage at 60 + 130 days	139	0.983
0	+	Tillage at 7 + 60 + 130 days	101	0.860
0.5	+	Tillage at 130 days	51	1.530
0.5	+	Tillage at 60 + 130 days	31	2.836
0.5	+	Tillage at 7 + 60 + 130 days	10	1.961
1.0	+	Tillage at 130 days	9	1.740
1.0	+	Tillage at 60 + 130 days	6	3.640
1.0	+	Tillage at 7 + 60 + 130 days	5	2.625
2.0	+	Tillage at 130 days	13	1.636
2.0	+	Tillage at 60 + 130 days	8	3.764
2.0	+	Tillage at 7 + 60 + 130 days	7	2.660

Adopted from Darwent, et. al. Can. J. Plant Sci. 1989.

This approach will not eliminate quackgrass from fields, but it does reduce quackgrass to acceptable levels.

Long-term research at Beaverlodge with glyphosate, post

emergent graminicides, tillage and crop rotations of canola, barley and under-seeded red clover indicates that similar results are possible in a variety of ways.

REDROOT PIGWEED

Amaranthus retroflexus

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed.

Emergence

Seeds require high soil temperatures to germinate. Seedlings emerge mainly in June and continue to emerge until fall if moisture conditions are adequate.

Flowers

Flowering is correlated with latitude, with northern populations flowering earliest. On average, flowering begins in early July and continues until mid-September.

Reproduction

Redroot pigweed is a heavy seed producer. Seeds will not germinate unless they are within two inches of the soil surface. Longevity of seeds appears to increase with depth of burial.

Seed longevity varies from 3 to 40 years. Redroot pigweed seeds are commonly found in clover and grass seed, especially alsike and timothy.

Competition

Redroot pigweed is a strong competitor in root crops and potatoes but does not compete as effectively with crops with narrow row spacings, especially if they are seeded early. Because redroot pigweed does not emerge until June, crops that are seeded early get a head start and compete well.

Management Strategy

Prevent seed production.

Control Mechanism

Tillage

Summer fallow - Redroot pigweed is prevalent on fallow land because it germinates after most weeds emerge and emerges after most summer fallow is tilled. Make a shallow tillage within four weeks of weed emergence. Older plants often recover from cultivation.

Pre-seeding tillage - Pre-seeding tillage warms the soil and encourages germination of redroot pigweed seeds.

Post-seeding tillage - Harrow cereals in the one-to-four leaf stage when seedlings emerge.

Fall tillage - Late fall tillage encourages germination of redroot pigweed seeds early in the following spring. If fall-tilled plants are nearing maturity, seed production can occur even when roots and stems are severed.

Rotation

Maintain clean summer fallow. Use weed-free seed for perennial forages. Most annual crops, except potatoes and field root crops do well in the rotation.

Seeding

Crops that are seeded early have a competitive advantage over later emerging redroot pigweed.

Mowing

Mowing is not effective. Older plants are able to recover and quickly produce axillary flowers.

RUSSIAN THISTLE

Salsola pestifer

Courtesy of DowElanco

Life Cycle

An annual, reproducing by seed.

Emergence

Seedlings emerge in early spring.

Flowers

Flowers appear from July until frost.

Reproduction

Seeds ripen from August through to frost and remain viable for up to three years. Plants break off at maturity and tumble across the land spreading seeds.

Competition

Russian thistle competes poorly with growing crops, but the stunted seedlings grow vigorously after crops are harvested.

Management Strategy

Prevent seed production.

Control Mechanisms

Tillage

Summer fallow - Badly infested fields will benefit from summer fallow. Plants should be buried, if possible.

Pre-seeding tillage - A shallow, early tillage encourages weed seed germination. The seeding operation destroys seedlings that have emerged.

Post-seeding tillage - To destroy Russian thistle seedlings in cereals, harrow before crop emergence or when the crop is in the one-to four-leaf stage.

Fall tillage - Cultivate after crops are removed to destroy weeds that survive in the crop. This is extremely important because Russian thistle growth is vigorous after crop removal and the weed can produce seed until frost.

Rotation

Include summer fallow in the crop rotation if Russian thistle populations are high. Any strong crop stand does well in the rotation as long as control measures are taken when the crop is removed.

Seeding

A shallow tillage plus seeding will destroy Russian thistle seedlings.

Mowing

Weeds larger than seedlings can be controlled by mowing if they become established in perennial crops or wastelands.

SCENTLESS CHAMOMILE

Matricaria perforata

Courtesy of Agriculture Canada

Life Cycle

An annual, biennial or short-lived perennial that reproduces by seed.

Distribution

Scentless chamomile is mainly present in central Alberta and the Peace River area. This weed is found in urban areas, roadsides, drainage ditches, fence lines, various crop lands, hay lands, pastures, farmyards and wasteland. It is more prevalent on disturbed sites and on Solonchic soils in areas of higher moisture, such as around sloughs and in depressions.

Germination

Scentless chamomile seed can germinate at temperatures

between 3 and 40° C, when the soil moisture is at more than 10 per cent of soil capacity. It can germinate at any time during the growing season especially during cool, damp weather. Most scentless chamomile seedlings establish in the spring or fall.

Scentless chamomile seed does not have a dormancy period. New seed requires light to germinate and will not germinate if buried in the soil. With time, scentless chamomile seed loses its requirement for light and will germinate in the dark. Buried seed can remain viable for up to 15 years.

Scentless chamomile seed germinates readily under periodic flooding conditions and this, along with the lack of competition, accounts for the growth around sloughs and other habitats prone to flooding.

Treatment	% germination
Seeds on surface of moist soil	84
Seeds on surface of soil saturated with water	82
Seeds buried 1 cm below soil surface	0
Seeds floating on water	70
Seeds on moist paper in a dish	94

Emergence and Growth

Annuals emerge in spring or early summer. The biennial forms emerge in summer or fall and overwinter as rosettes. Short-lived perennials emerge in spring or summer and produce seed two years in succession, early in the season.

Flowers

Scentless chamomile flowers from May to October. Flowers can be produced within 58 days of germination. In a non-competitive situation, annuals begin to flower in early July. In a competitive crop situation, flowering does not generally occur until the crop is removed. Overwintering biennials and short-lived perennials usually begin to flower in mid-May or early June.

Scentless chamomile has an indeterminate flowering habit; therefore, flowers and seed are continually formed. At any one time, these plants can have flowers, immature seed and mature seed. This growth habit makes eradication difficult.

Reproduction

Seed

Abundant seed production and variable dispersal methods are scentless chamomile's key to success. The seed can be widely dispersed on equipment and as a contaminant in crop seed and feed. Dispersal by water is also common.

Facts about scentless chamomile seed

1. A single plant can produce as many as one million seeds.
2. In a dense stand as many as 1.8 million seeds/m² may be produced.
3. One flower head can have as many as 300 seeds.
4. The seeds develop quickly. As soon as the flower is formed, the seed is viable.
5. Biennial and short-lived perennial forms set seed as early as mid-June.
6. Flowering and seed production are best under high light intensity.
7. The ribs on the small, light seed allow for ready spread by wind and water.
8. The seed can float in water for at least 12 hours.
9. As much as 26 per cent of seed fed to cattle remains viable in the manure.

Competition

Scentless chamomile does not grow well in a competitive crop. If scentless chamomile becomes established on bare soil or in weak plant stands, it can become very aggressive and cause significant crop yield losses.

Yield loss of wheat from scentless chamomile at 25 plants/m²

Form of scentless chamomile	Crop	Growth conditions	Yield loss
Spring-emerging annual	Spring wheat	Cool, wet	55
Spring-emerging annual	Spring wheat	Drought	0
Fall-emerging biennial	Spring wheat	Moderately moist	60
Fall-emerging biennial	Spring wheat	Drought	20
Fall-emerging biennial	Winter wheat	Moderately moist	6
Fall-emerging biennial	Winter wheat	Drought	3

Once scentless chamomile has overwintered in the biennial or short-lived perennial form, it becomes more competitive and more difficult to control. A single plant growing without competition may cover an area in excess of a square metre. Seedlings that emerge in the spring will often form a very dense carpet in low-lying areas and limit growth of seedlings of other species.

Management Strategy (Lines of Defense)

Prevent introduction into an area

To prevent the introduction of scentless chamomile in your area

- a) use clean seed,
- b) tarp your grain trucks,
- c) clean your farm and industrial equipment before movement out of an infested area,
- d) feed cattle feed contaminated with chamomile only in a contained area and treat the area annually to prevent seed production.

Prevent seed production by initial infestations

Pulling the first scentless chamomile plants in an area before the flowers are fully formed can prevent an on-going, costly and troublesome problem in the future. Spot treatment in and around these small initial infestations with a residual selective herbicide will help prevent the establishment of scentless chamomile in new areas. These initial infestations should be closely monitored over the next several years. Fencelines, headlands, drainage ditches and waste areas that are kept free of scentless chamomile will help to prevent this weed from spreading into cropland.

Scentless chamomile seed viability at specific flowering stages

Flower stage	% germination
Early flower	0
Full petal	71
Late flower	88
Early senescence	86
Seed set	86

Prevent establishment of overwintering scentless chamomile

Tillage or spraying of infestations in the late fall or early spring will control rosettes before they become more established and difficult to control. Fall spraying is especially important with reduced tillage management.

Use competition to advantage

Scentless chamomile will not compete with a heavy crop stand. The key is to establish a good crop stand as quickly as possible and maintain it in that state. The chamomile will be crowded out by a good forage stand as indicated by the graph.

Scentless chamomile in alfalfa-timothy near Leduc, Alta.

Control Mechanisms

Tillage

Tillage effectively controls scentless chamomile seedlings. Frequent shallow tillage will aid in the germination and destruction of seedlings. Once the plant has overwintered

and developed a crown and an extensively branched fibrous root system, more thorough tillage followed by harrows is required to dislodge the soil from the root system. Till, if possible, on hot, dry days to ensure that the root system dries quickly. Tillage operations should be carried out before flowering to insure a reduction in the seed bank.

Pre-seeding tillage - Spring cultivation destroys seedlings and any scentless chamomile plants that overwinter. Cultivation should be followed in two days by harrowing to break up root balls.

Post-seeding tillage - In emergencies, harrow cereals after seeding to destroy later emerging weed seedlings. Post-seeding tillage should not be a substitute for pre-seeding tillage.

Fall tillage - Cultivate after harvest to prevent seed set of the weeds that have been suppressed by the crop. Fall tillage also destroys biennial and short-lived perennial forms of scentless chamomile.

Mowing

Mowing can be used to reduce seed production in pastures, hay land and non-crop land. The plants should be cut before the flowers are fully formed. Unfortunately, scentless chamomile will form new flowers below the cutting height of the swather or mower in the leaf axils. Scentless chamomile needs to be mowed early and often with each successive mowing lower than the previous one.

Hand pulling

Hand pulling and burning is the most effective method to prevent the spread of scentless chamomile into new areas. Pulling the first few plants along a roadside before they go to seed may prevent a new infestation.

Biological control

Two insects are being evaluated for use in Canada. *Apion hookeri*, a seed-head feeding weevil from Germany, and *Ceutorhynchus edentulus*, a stem-mining weevil from Austria, show promise as biological control agents for controlling scentless chamomile. *Apion hookeri* was released in Alberta in 1992.

Rotations

Scentless chamomile thrives when competition is weak. This weed is often a problem the year after under-seeding a crop with a forage. At this time, forage crop growth is usually slow and there is a lack of available control methods when a legume is present in the forage mix. Any practices that aid in the establishment of the forage, such as seeding good forage seed shallowly into a firm moist seedbed, will help in reducing the scentless chamomile growth. As the forage crop matures, the forage usually provides sufficient competition to crowd out the scentless chamomile. A healthy grass stand provides effective competition

and chamomile can be selectively removed from grass stands with a herbicide.

In established forage stands, scentless chamomile will only be a problem where the forage is not growing well. This may be in an area of Solonchak soil or where the stand is being overgrazed. Fertilizer will help maintain a competitive forage stand, but generally cultivation and reseeding is required when the stand has deteriorated. Scentless chamomile is of low nutritive value and is not freely grazed by livestock.

Canola and cereal crops compete well with scentless chamomile, especially when seeded at slightly higher than normal seeding rates. However, infestations can develop when tillage or herbicides are not used to kill plants that overwinter and seedlings that emerge before or just after the crop. Lentils and flax do not compete effectively for light and thus scentless chamomile can be a serious problem in these crops.

Herbicides

Seedlings are relatively easy to control compared to plants that have overwintered. The earlier the application of herbicide, the more effective the control of both forms. A herbicide application is not cost effective when most of the scentless chamomile is flowering because the seed has already been produced and the yield loss has occurred. Total vegetation control herbicides such as Roundup and Sweep should not be used to control scentless chamomile where other vegetation is growing. All vegetation will be controlled or suppressed, leaving no competition for new emerging scentless chamomile. Consult the current edition of *Crop Protection With Chemicals*, Agdex 606-1 for herbicides registered for the control of scentless chamomile in the different crops.

Multi-technique approach

A combination of tillage, herbicide and competitive cropping can be very effective in managing scentless chamomile. The goal of these techniques is to prevent seed production and crowd out infestations through crop competition.

SHEPHERD'S-PURSE

Capsella bursa-pastoris

Courtesy of DowElanco

Life Cycle

Summer and winter annual that reproduces by seed.

Emergence

Summer annuals emerge mainly in late spring and produce flowers and seed throughout the summer. Winter annual seedlings emerge in late summer, overwinter and continue to grow the following spring.

Flowers

Summer annuals flower from the end of June until fall. Winter annuals produce flowers from the overwintered rosettes in early spring and continue flowering throughout the summer.

Reproduction

Seeds can germinate when mature or go dormant and remain viable in the soil for up to 30 years.

Competition

Shepherd's-purse is a strong competitor in seedling crop

stands. It will not compete with strong, established crops.

Management Strategy

Prevention of seed production and control of fall growth of winter annuals are the keys to controlling shepherd's-purse. As a winter annual, this weed can flower and produce seed in early spring before fields can be worked and before perennial forages require mowing.

Control Mechanisms

Tillage

Summer fallow - The first tillage in spring destroys seedlings and winter annuals. Till in summer, when necessary, to control seeds that germinate later in the season. Fall tillage controls the winter annual rosettes.

Pre-seeding tillage - Make a shallow tillage in early spring if overwinter weeds are a problem. Seeding operations will destroy most seedlings that emerge in the spring. If possible, delay seeding until the main flush of weeds emerges.

Post-seeding tillage - If tillage is done before or during the seeding operation then post-seeding tillage should not be required.

Fall tillage - Fall tillage controls rosettes that would otherwise overwinter and stimulates germination of annual weed seeds. Make a shallow tillage in early October with an implement that will preserve crop residue.

Rotation

Crop rotation alone will not eliminate this weed since it can be a problem in all crops. Summer fallow will help reduce seed reserves in the soil.

Seeding

Delay seeding until late spring when the main flush of summer annual seedlings has emerged. Shallow tillage at or before seeding will destroy the seedlings. Seed an early maturing crop immediately following tillage. Increase seeding rates, up to 25 per cent heavier than normal, to give the crop competitive advantage over shepherd's-purse, provided there is adequate moisture.

SMARTWEEDS — ANNUAL

Polygonum spp.

Courtesy of DowElanco

Life Cycle

Annuals that reproduce by seed.

Emergence

Seedlings emerge mainly in rich moist soils in early to midspring.

Flower

Smartweeds flower inconspicuously from July to October.

Reproduction

Seeds mature from late July through to frost, and can remain viable for up to 50 years. Smartweed seeds are difficult to separate from flax seed and clover seed.

Competition

Strong stands of annual cereals and perennial forages will

compete with annual smartweed. Flax and most specialty crops will not compete. Smartweeds can delay harvest because they slow the drying of the swaths.

Management Strategy

Prevent seed production and encourage germination of existing seed.

Control Mechanisms

Tillage

Summer fallow - Annual smartweed is controlled by repeated tillage. However, seed reserves in the soil usually cause re-infestation the year after summer fallow.

Pre-seeding tillage - Seedlings emerge from shallow depths. Thus, a shallow pre-seeding tillage will encourage seed germination. The seedlings are destroyed during the seeding operation.

Post-seeding tillage - Harrow to eliminate smartweeds that emerge after cereals are seeded. Harrow before the crop emerges or when it is in the one to four-leaf stage, prior to tillering.

Fall tillage - Fall tillage brings seed to the surface and encourages germination.

Rotation

Perennial forage crops compete for moisture and discourage growth of smartweed. Strong cereal stands suppress growth of annual smartweeds. Low-lying areas can be seeded to grasses. Summer fallow will prevent seed production and decrease seed reserves in the soil.

Seeding

Cereals that are seeded at rates heavier than normal have increased competitive ability. Tillage during the seeding operation will eliminate existing weed seedlings.

Mowing

Frequent mowing of grass seeded in low areas controls annual smartweed until the grass is well-established.

SMARTWEED — PERENNIAL

Polygonum spp.

Courtesy of Agricultural Research Service U.S.D.A.

Life Cycle

A perennial that reproduces mainly by creeping root stocks.

Emergence

New vegetative growth emerges in late May and early June. Seeds germinate in mid-spring.

Flowers

Flowers appear from late June to September.

Reproduction

Seed

Viable seeds are seldom produced in Alberta.

Vegetative

On dry land, plants reproduce by sending up shoots from coarse, woody, underground stems. Plants in water reproduce from floating branches.

Competition

Perennial smartweeds are strong competitors with forages and field crops; once established they become the predominant species. Fall rye and barley compete the best with this weed. Control of established stands may require taking the land out of production.

Management Strategy

Prevent the spread of these weeds and starve the root systems. It is critical to control patches of these weeds so that they do not become a field scale problem.

Control Mechanisms

Tillage

Tillage is an ineffective way of controlling of perennial smartweeds and will only serve to spread them.

Summer fallow - Chemical fallow, mowing and grazing are the only means that limit perennial smartweed growth.

Pre-seeding tillage - Shoots emerge late so pre-seeding tillage is ineffective and may cause the spread of these weeds.

Post-seeding tillage - Post-seeding tillage is ineffective and may cause spread of the weed.

Fall tillage - Chemical application after crop removal may aid in weed suppression. Tillage is not effective.

Rotation

Chemical control may require that the land not be in production. Residues of herbicides, depending on what is used, may limit which crops are grown. Fall rye and barley offer the most competition in areas surrounding the weed patches.

Seeding

Avoid seeding infested areas because root disturbance encourages weed spread.

Mowing

Mow or graze to eventually weaken the root system. This does not kill established weeds. This species tends to persist where the land is wet. Mowing may not be possible.

SOW-THISTLE — PERENNIAL

Sonchus arvensis

Courtesy of Agriculture Canada

Life Cycle

A persistent deep-rooted perennial spread by wind dispersed seed and fleshy horizontal creeping roots. The roots are readily broken. Root pieces with buds can produce new plants.

Distribution

Percentage of fields containing perennial sow thistle

Agricultural region	Percentage
Region I (Lethbridge area)	1
Region II (Calgary area)	2
Region III (Red Deer area)	1
Region IV (Vermilion area)	10
Region V (Barrhead-Edmonton area)	26
Region VI (Peace River area)	43

Most field infestations of perennial sow-thistle are in the three northern regions. In southern Alberta this weed occurs on irrigation canal banks, roadside ditches and other areas of high soil moisture.

Under cultivation, it is present primarily in patches. Field scale infestations are infrequent except in freshly-broken land.

Germination

Some seeds are capable of germination even when the plant is mowed five days after pollination. Maximum seed germination is reached seven to nine days after flowering. The seed of plants that are mowed during flowering continue to mature on the mowed stems if the tissue remains moist. If prevention of seed is to occur, the sow-thistle plant should be mowed before flowering has started.

Emergence and Growth

Sow thistle is a shallow germinator. Most seedlings emergence from depths of less than 0.5 cm. Emergence will not occur if seeds are buried more than 3 cm deep. As a result, cultivation that buries seed more than 3 cm deep provides excellent control. Seedlings survive best where there is surface litter and high moisture, as compared to open cultivated fields. This characteristic contributes to establishment of sow thistles under minimum-till production, field margins and along ponds and ditches. The removal of the moisture in the top 3 cm of soil prevents germination and helps control perennial sow thistle.

Reproduction

Seed

Seed is spread primarily by wind. However, the hooked cells at the end of the pappus hairs allows seeds to cling to clothes, fur and other objects. Approximately 80 per cent of the seed germinates in the year after production. Seedling survival, however, is low. While seed can be transported by water in streams and irrigation canals, it completely rots after only three months in fresh water. To germinate seed of perennial sow thistle requires a continual supply of moisture. This explains why this weed is a greater problem on moist areas, during wetter years and in areas where water fluctuation occurs.

Sow thistle seed does not germinate until the soil temperature is 25-20°C (mid to late May). This growth pattern does not allow for much control before spring seeding.

Because plants in a clone are not self-compatible, seed production in isolated patches is poor. However, where plants from more than one clone are present in a field, high rates of seed production can occur.

Vegetative

Buds on spreading roots, vertical roots and underground portions of the aerial stems can all produce new plants if roots are broken into pieces. Plants can be produced from root sections less than 1 mm long if well developed buds are present. The resulting plants can flower in one year. Sow-thistle roots have a natural dormancy that inhibits shoot emergence from vegetative buds in the fall. As a result, fall application of herbicide is generally not an option for the control of perennial sow thistle as is the case

with Canada thistle. However, breaking the roots into pieces and exposing them to drying and frost during the winter months could reduce their viability.

While not rapid, the horizontal spread by creeping roots is substantial. If left undisturbed, a patch of sow thistle can increase from 0.5 m to 3 m in diameter in one year.

Competition

Sow-thistle appears to accumulate potassium and may compete strongly for this element with alfalfa, winter wheat, barley, canola and sugar beets. This competition represents an average of about a 1 per cent yield loss in canola in Western Canada. However, 5 shoots/m² produce a 12 per cent loss and 10 shoots/m² produce a 18 per cent loss. Therefore, yield loss can be substantial in sow thistle patches.

Either alfalfa or perennial grasses provide strong crop competition to sow thistle.

Management Strategy

- Reduce weed competition.
- Prevent seed production.
- Exhaust root reserves on established sites.

Control Mechanisms

Tillage

To prevent seedling establishment, the most suitable date for tillage is the six-leaf rosette stage. The seven- to nine-leaf rosette stage seems to be the critical stage for tillage to reduce the reproductive capacity of sow thistle roots. The success of tillage depends on the depth of burial and the degree of root breakage. If root pieces are left on the soil surface, they will dry up, and if buried more than 30 cm deep, less than 10 per cent of the new plants will emerge. Increased root breakage increases the number of buds that produce shoots and ultimately results in increased root reserves if timely tillage does not occur to control top growth. The smaller the root piece, the less vigorous the resulting plant will be.

Dry conditions are a major growth inhibitor. Sow thistle will not appear to be a major weed during dry years. Any physical or chemical control measure applied during this time will have a greater impact than during moist soil conditions.

Mowing

Mowing is less effective than tillage.

Grazing

Grazing infested land effectively reduces stands because the weed is palatable to sheep and cattle but is not their preferred fodder.

Multi-technique approach

Control of perennial sow-thistle often requires a combination of cultural and chemical treatments to reduce competition, prevent seed production and reduce food storage and reproductive capacity of roots.

Increase competitive ability of crops:

- Grow competitive crops such as perennial grasses.
- Drill fertilizer with seed or band fertilizer to make it more available to the crop.
- Plant solid crop stands instead of row crops.
- Plant tall varieties rather than semi-dwarf varieties.

Prevent seed production:

- Apply in-crop herbicides on large acreages.
- Mow patches or spray patches with a total vegetation control herbicide.
- Produce silage as an emergency measure in heavily infested fields.

Reduce the reproductive ability of roots:

- Till to chop roots into small pieces.
- Leave root material on the soil surface to be desiccated by frost and wind.
- Apply an in-crop herbicide to limit the amount of food reserves.
- Fallow with chemical and mechanical methods.

The control varied from 60 per cent to 98 per cent depending on the herbicide used when the following combination of treatments were applied: herbicide application in summer fallow - June; two discings - August; two cultivations - September - October; one cultivation before seeding the following year. Where soil erosion is a major factor, some cultivation could be substituted by a herbicide treatment.

Biological control

A gall-midge, *Cystiphora sonchi*, that attacks perennial sow-thistle has been established in Alberta. Adults are small, delicate, short-lived and rarely seen. The insect causes galls on the leaves that are pimple-like swellings, 3-4 mm in diameter, in which the midge larvae live. Over 200 galls can occur on one leaf. The insect is well established and has increased at one release site in Alberta. Studies are under way to determine whether it causes significant damage to perennial sow-thistle. If this is confirmed, a supply of the insect will be available for redistribution. Another insect, a gall-fly that feeds on the flowers of perennial sow-thistle, has been tested but does not seem able to overwinter successfully under prairie conditions.

STINKWEED

Thlaspi arvense

Courtesy of Agriculture Canada

Life Cycle

A summer and winter annual that reproduces by seed.

Emergence

Emergence of summer annuals occurs mainly in early spring. Seeds of winter annual germinate in late summer; seedlings overwinter and continue to grow in the spring.

Flowers

Winter annuals can flower in early spring. Flower and seed production of both forms take place throughout the summer.

Reproduction

Stinkweed seed can live for up to six years in the tillage zone. Seeds that are buried deeper than the tillage zone can live for up to 20 years and germinate when they come close to the surface. Dormancy of stinkweed seeds is encouraged by a thick seed coat.

Competition

Stinkweed can compete with crops for moisture and nutrients.

However, a well-fertilized crop that has a head start over stinkweed will compete well.

Management Strategy

Control of fall rosettes of winter annuals is important so that seed is not formed early the following spring. During any tillage operations plants with developed pods should not be turned under because they can continue to ripen on the stalks in warm soil.

Control Mechanisms

Tillage

Summer fallow - Till early in the spring after stinkweed emerges. Make a shallow tillage in summer if needed. Fall tillage will control the winter annual rosettes.

Pre-seeding tillage - To minimize competition with the crop, control weed seedlings in the spring with a shallow tillage operation before or during the seeding operation. If overwintered stinkweed is a problem, till early in the spring.

Post-seeding tillage - Post-seeding tillage should not be required if pre-seeding tillage is done, or if seeding is after the main spring weed emergence.

Fall tillage - Fall tillage controls rosettes that would otherwise overwinter and stimulates germination of annual weed seeds. Shallow tillage in early October with a field cultivator will conserve some crop residue and destroy weed seedlings.

Rotation

Crop rotation alone will not control stinkweed. A summer fallow year in the rotation will help to reduce seed levels in the soil. Seedlings will still germinate from existing seeds.

Seeding

Seed after the main weed seedling emergence. Waiting for stinkweed to emerge may delay seeding slightly.

Mowing

Mowing prevents seed production but short plants may escape cutting.

STORK'S-BILL

Erodium cicutarium

Courtesy of Manitoba Agriculture

Life Cycle

Stork's-bill is reported to act as an annual, biennial or winter annual. On cultivated land in Alberta, this weed grows mainly as an annual.

Emergence

Main emergence is in mid-spring and continues through the summer.

Flowers

This weed flowers from early July through August.

Reproduction

Seeds readily germinate after tillage operations. Seeds remain viable for one to three years in the soil. Cleaning stork's-bill seed from crops that have small seeds can be difficult.

Competition

Soil disturbance during seeding encourages a flush of stork's-bill seedlings to emerge. These weeds emerge with the crop and compete strongly with it. Stork's-bill grows very dense

and can withstand drought. It takes moisture from the crop and can cause severe yield reductions in dry years. Heavily seeded, vigorous crop that have a head start over stork's-bill compete well. Fall rye provides good competition in light soils.

Management Strategy

Prevent seed production.

Control Mechanisms

Tillage

Summer fallow - Stork's-bill is persistent on summer fallow because new flushes occur after each tillage. Each flush of weeds must be controlled before seed production. Repeated shallow tillage controls existing weeds and stimulates new weed growth and eventually exhausts seed reserves in the soil.

Pre-seeding tillage - Early, shallow cultivation encourages germination of stork's-bill seeds. These seedlings can be destroyed with a second spring tillage at or before seeding. The date of seeding may be delayed slightly.

Post-seeding tillage - Post-emergent cultivation with a harrow may give some control of stork's-bill in deep-seeded cereal crops.

Fall tillage - Late fall tillage controls the biennial or winter annual rosettes that would otherwise overwinter and flower the following year.

Rotation

Stork's-bill is very competitive, so infested fields should be summer fallowed or seeded to a competitive crop. Fall rye is a good crop choice. Seed production of stork's-bill is prevented by an early harvest of fall rye.

Seeding

Spring seeding may be delayed if two tillage passes are required to kill emerging stork's-bill. If the need for post-seeding tillage is anticipated, then a cereal crop should be planted. Seeding of winter annual crops should be done after fall emergence of winter annual stork's-bill.

Mowing

Mowing is only partially effective for controlling seed production of stork's-bill. This low growing weed will likely be missed by the mower.

TARTARY BUCKWHEAT

Fagopyrum tataricum

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed.

Emergence

The main seedling emergence is in early to mid-spring with sporadic germination throughout the summer.

Flowers

Flowers are produced four to five weeks after plant emergence and the weed continues flowering until fall. Tartary buckwheat has an indeterminate growth habit, so the same plant can have flowers, immature seed and mature seed at the same time.

Reproduction

Seeds of tartary buckwheat ripen three to four weeks after flowering. Mature seeds germinate after four to five weeks in warm, dry conditions or go dormant in cool, moist conditions. Seeds remain viable for up to three years. Dormancy lasts for the same amount of time. Seeds of wild and tartary buckwheat are the most common impurities of cereals and account for a large percentage of dockage.

Competition

Tartary buckwheat is a strong competitor and is responsible for dockage in cereal grains. Its seed is similar in shape and size to cereal seed, so cleaning is difficult. The following table shows estimated yield losses of barley and wheat caused by tartary buckwheat. Actual yield losses may vary from year to year depending on climatic conditions.

Tartary buckwheat plants /ft ²	Per cent yield loss	
	Barley	Wheat
0.5	7	12
1	10	15
2	14	19
3	16	22
5	21	27
8	26	33
10	29	37
15	36	44
20	41	50

Management Strategy

Eradication of tartary buckwheat seedlings and sowing clean seed are the strategies to follow for control of this weed.

Control Mechanisms

Tillage

Summer fallow - Because of the short dormancy period and viability of tartary buckwheat seeds, summer fallow can effectively control this weed. Tillage encourages germination of wild buckwheat seeds and subsequent tillage destroys the seedlings.

Pre-seeding tillage - Early, shallow tillage encourages germination. When the seedlings emerge the land should be tilled and seeded. Seeding will be delayed about 10 days and some surface moisture will be lost.

Post-seeding tillage - Post-seeding tillage should be done in cereals only, when other control measures are not feasible.

Fall tillage - If warm, dry weather follows harvest then shallow fall tillage will encourage germination of tartary buckwheat seeds; the resulting growth is winter-killed. If conditions after harvest are cold and wet, the weed seeds will not mature properly and tillage should be left until spring so that dormant seeds are not buried.

Rotation

Summer fallow and forage crops will help to reduce tartary buckwheat populations.

Seeding

Delay spring seeding about 10 days so that weed seedlings are destroyed by tillage. At other times till before seeding if tartary buckwheat is a problem.

Mowing

Mowing delays shoot growth of tartary buckwheat but seed production resumes because of the plant's indeterminate growing habit. In forages, two cuttings per season are necessary to reduce tartary buckwheat populations.

TOADFLAX

Linaria vulgaris

Courtesy of DowElanco

Life Cycle

A perennial that spreads by seeds and creeping roots.

Emergence

New shoots and seedlings emerge throughout the season, beginning in midspring. Seeds germinate from very shallow depths and will germinate on the soil surface.

Flowers

This weed flowers from June through fall, with shoots flowering earlier than seedlings.

Reproduction

Seed

Toadflax seeds have no dormancy period and can germinate as soon as they are shed. They remain viable for up to three years in the soil.

Vegetative

New shoots emerge from deep, running root stocks. The roots store food for the weed.

Competition

Toadflax is a strong competitor. Perennial and annual grasses offer the most competition against this weed.

Management Strategy

Prevention of seed production and root starvation are the key to control.

Control Mechanisms

Tillage

Summer fallow - Apply the principal of root starvation.

Cultivation every three to four weeks, beginning in June, will control but not eliminate toadflax. Where wind erosion is a serious problem, work the land in alternate 80 m (87 yd) wide strips of crop and fallow. Alternate these strips the following year.

Pre-seeding tillage - Tillage before seeding will remove top-growth and give crop seedlings a better chance for establishment.

Post-seeding tillage - This is not effective for control of established stands of toadflax but can destroy existing weed seedlings in cereals. Tillage must be very shallow so that toadflax roots are not spread. However, tillage will encourage a flush of weed seedlings when seeds are brought to the surface.

Fall tillage - Begin tillage as soon as the crop is harvested. Regrowth between tillage operations should not remain above ground for more than five to eight days, until top growth is killed by frost.

Rotation

Alternate fallow and crops to reduce toadflax stands in cereals and prevent interference with grain production. Three cycles of this rotation can reduce toadflax stands by 90 per cent. Fall rye is a good crop to choose for this rotation. Two grain crops can follow a year of intensive cultivation without dramatic increases in the toadflax stand. Post-harvest and pre-seeding tillage are required in this rotation. A perennial grass can follow a year of summer fallow. Bromegrass or crested wheatgrass will compete well against toadflax.

Seeding

Seed cereals at a rate heavier than normal to compete well with toadflax stands.

Mowing

Mowing helps to decrease seed production but will not eliminate toadflax stands.

Biological control

Two insects are already widely established on most toadflax infestations in Alberta, a small beetle, *Brachypterolus pulicarius*, and a weevil *Gymnaetron antirrhini*. They feed in the flowers and prevent seed production.

Brachypterolus pulicarius usually appears earlier in the year, damages the tips of the flowering shoots and prevents development of many flowers. Check the flowers on toadflax infestations for these insects. *B. pulicarius* is a small, black, shiny, flat beetle about 2-3 mm in length. *G. antirrhini* is usually less abundant; it is slightly larger, rounder, duller and dark grey. If these insects are not present, they can be introduced by placing infested toadflax branches among the flowering shoots of toadflax. Take care not to spread toadflax seed around with the insects.

Another insect is being tested in Alberta, the moth *Calophasia lunula*. The caterpillars of this moth feed on the leaves and flowers of toadflax. They are striking in appearance; the caterpillars are mottled with yellow, black and grey and up to 3 cm in length when full grown. This insect has been established in Ontario since 1962 and is sometimes abundant enough to completely defoliate small patches of toadflax. This insect bred and overwintered in Alberta on the initial release.

For identification of these insects, or to inquire about where to obtain them, contact the Alberta Environmental Centre or Alberta Agriculture, Food and Rural Development.

WHITE COCKLE

Silene alba

Courtesy of Agriculture Canada

Life Cycle

White cockle is a fleshy-rooted biennial or short-lived perennial that sometimes behaves as an annual. This weed reproduces mainly by seed or from buds on crown-root segments.

Emergence

Seed germination occurs from early spring through fall.

Flowers

This weed flowers from June to October. The earliest flowers are from plants that have overwintered.

Reproduction

Seeds

White cockle is a prolific seed producer. Seed matures in capsules four to five weeks after flower formation. Immature seeds can be viable two to three weeks after pollination. Seed is viable for one to three years and a short dormancy may occur. White cockle seed requires light for germination, so tillage encourages germination.

Vegetative

Plants may form from crown-root segments with as little as 1 cm of root attached. Till during dry weather so that crown-root segments can not re-root.

Competition

White cockle can be competitive in the year of forage establishment, but after harvest the competitive effects are less severe. Strong stands of annual crops offer competition against white cockle.

Management Strategy

Prevent seed production, Plant weed-free seed.

Control Mechanisms

Tillage

Summer fallow - Deep cultivation will destroy white cockle during dry weather. Seed reserves in the soil will decrease if plants do not produce seed.

Pre-seeding tillage - Early spring tillage destroys plants that overwinter and encourages germination of seeds by exposing them to light. A second spring tillage at seeding destroys any seedlings.

Post-seeding tillage - Because shallow tillage encourages the germination of white cockle seeds, post-seeding tillage is not recommended.

Fall tillage - Carbohydrates are stored most rapidly in September and early October. Cultivation should follow this period and be deep enough to cut below the crowns of the white cockle plants. Cut the roots completely because new plants can form from root pieces.

Rotation

Include only summer fallow or annual crops in the rotation if infestations are severe. Perennial forage seed often contains white cockle seed. White cockle will persist in a perennial stand that is not disturbed.

Seeding

Tillage before seeding will promote germination of weed seeds and will help to decrease white cockle populations. Tillage destroys seedlings that have emerged.

Mowing

Mowing when the plants are in flower weakens white cockle and prevents seed production. Secondary growth may emerge from crown buds in response to mowing.

WILD BUCKWHEAT

Polygonum convolvulus

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed.

Emergence

Most seedlings emergence in midspring in association with the first prolonged warm period. Sporadic seed germination occurs throughout the growing season. Germination takes place in the top 5 cm of soil.

Flowers

Wild buckwheat has an indeterminate flowering habit, so the same plant can have flowers, immature seed and mature seed at the same time. This weed flowers from May through October.

Reproduction

Seeds of wild buckwheat do not appear to live longer than three years. After maturation, seeds can germinate in four to five weeks if weather conditions are warm and dry. If conditions are cool and wet, seeds will go dormant. Dormancy can last for up to three years. Seeds of wild and tartary buckwheat are the most common impurities of cereals and account for a

large percentage of dockage. Wild buckwheat seeds make good feed for poultry.

Competition

Wild buckwheat grows toward the light and entangles crop plants. This weed can cause crops to lodge. Wild buckwheat becomes entangled in machinery, particularly during harvest.

Management Strategy

Use weed-free seed and destroy seedlings.

Control Mechanisms

Tillage

Summer fallow - Summer fallow can effectively control this weed because its seeds have a short period of dormancy and viability. Tillage encourages germination of wild buckwheat seeds, and subsequent tillage destroys the seedlings.

Pre-seeding tillage - Early, shallow tillage encourages germination. Till and seed when the seedlings emerge. Seeding will be delayed by as much as 10 days and some surface moisture will be lost.

Post-seeding tillage - Use post-seeding tillage only in cereals when other control measures are not feasible.

Fall tillage - If warm dry weather follows the harvest, shallow fall tillage will encourage germination of wild buckwheat seeds; the resulting growth is winter-killed. If conditions after harvest are cold and wet, the weed seeds will not mature properly and tillage should be left until spring so that dormant seeds are not buried.

Rotation

Summer fallow and forage crops will help to reduce wild buckwheat populations.

Mowing

Mowing inhibits wild buckwheat growth but seed production resumes because of the plant's indeterminate growing habit. In forages, two cuttings per season are necessary to reduce wild buckwheat populations.

WILD MUSTARD

Sinapis arvensis

Courtesy of DowElanco

Life Cycle

An annual that reproduces by seed.

Emergence

The main flush of seedlings is in early spring with sporadic germination throughout the summer.

Flowers

Wild mustard flowers from May through fall.

Reproduction

Seed matures six weeks after full flower and can germinate as soon as the seed falls to the ground. Seeds that are buried immediately go dormant. Dormancy is a result of low oxygen levels beneath the soil surface. Seeds can remain viable for up to 60 years in the soil.

Competition

In early spring wild mustard has a competitive advantage over crops because of its rapid early growth. However, this weed requires high light intensity to grow well and does not compete with heavily seeded, well-fertilized crops.

Management Strategy

Seeds of wild mustard are viable for up to 60 years and are easily spread with canola seed. For these reasons, clean seed and the prevention of weed seed formation are extremely important in the control of wild mustard.

Control Mechanisms

Tillage

Summer fallow - Wild mustard seedlings are easily killed with cultivation. The first tillage should be in mid to late spring when the main flush of weeds has emerged. Follow with additional tillage only when required.

Pre-seeding tillage - Shallow tillage at or before seeding will destroy existing weed seedlings.

Post-seeding tillage - If weed seedlings are controlled at or before seeding then post-seeding tillage should not be required.

Fall tillage - Fall tillage is required only if weeds that emerged late in the season will produce mature seed before freeze-up.

Rotation

Wild mustard is not eliminated through crop rotation because seeds remain viable in the soil for up to 60 years. Perennial forage crops discourage germination of wild mustard seeds. The seeds remain dormant when oxygen is not available.

Seeding

Seed as early as the land can be tilled. This allows the crop to be competitive with wild mustard that emerges earlier in the season.

Mowing

Mowing keeps wild mustard from going to seed. Fall mowing destroys weeds if fall tillage is not possible.

WILD OATS

Avena fatua

Courtesy of Agriculture Canada

Life Cycle

An annual grass that reproduces by seed.

Distribution

Wild oats occur in almost all cultivated fields in Alberta but are less severe in the south-east of the province.

Fields with wild oats after a herbicide treatment

Region		Percentage
Region I	(Lethbridge area)	27
Region II	(Calgary area)	29
Region III	(Red Deer area)	54
Region IV	(Vermilion area)	61
Region V	(Barrhead-Edmonton area)	55
Region VI	(Peace River area)	67

Germination

Wild oats germinate throughout the growing season. The main flush occurs in the spring with a secondary flush in the fall. The germination period varies as much as three weeks, depending on weather conditions. Under warm and moist conditions, the main flush can occur over a short period of time and before crop emergence. Under prolonged cool weather, germination may continue until after the crop emerges.

The optimum soil temperature for the germination of wild oats is between 16 and 22°C. Germination is slow at 4°C and very slow at 33°C. Most germination occurs at depths of 2 to 5 cm if soil moisture is adequate. However, if the surface layer is dry, germination can occur at depths up to 20 cm.

The wild oat seed will not germinate while exposed to light; it must be buried. Seed can be buried naturally by wind drifted soil, soil washed by water or through its unusual self-burial process. When wild oat seed is moistened, the awn unwinds. As the seed dries out the awn twists again. Alternate wetting and drying enables the wild oat to bury itself, thereby satisfying one condition for germination.

Emergence and Growth

Most wild oats germinate and emerge in early to mid-spring. Cool, moist conditions promote maximum emergence, so crops that are seeded early are usually the most heavily infested. Fall or early spring applications of nitrogen fertilizer stimulate germination. Growth of roots and shoot of wild oats is slow for the first two weeks, but increases quickly from then on. Most wild oats tiller within a month of emergence.

Flowers

Wild oats usually start to flower in early July and may continue to flower for up to six weeks. Seeds at the tip of the main axis of the panicle may ripen and fall to the ground before the seeds at the base are filled. Seeds shatter as they mature and are shed by mid-August, generally before the crop is harvested.

Reproduction

Seed

Mature seeds of wild oats are usually dormant when they shatter. Dormancy is broken by warm, dry conditions after the seeds ripen. If moisture is available when dormancy is broken, the seeds will germinate; otherwise they become dormant again.

The annual rates of seed germination are:

- The spring following seeding - up to 80 per cent.
- The second spring following seeding - up to 97 per cent.
- The remaining 3 per cent may have what is termed deep-seated dormancy and can germinate for up to 12 years.

Vegetative

Though not a major method of reproduction, wild oats are capable of vegetative regeneration. Wild oat plants can be transplanted and regrown if cultivation is incorrectly or incompletely carried out, and field and weather conditions are good for plant growth. Even severely injured (mutilated, sectional or segmented) wild oat plants are capable of vegetative propagation.

Competition

Competition is greatly influenced by the relative emergence dates of wild oats and the crop. If wild oats emerge before the crop, yield losses are greater than when the crop emerges first. Density and rates of growth of the weed and the crop alone influence competition. Increased growth rates and densities of wild oats increase crop yield losses. The following table shows the estimated yield losses caused by various densities of wild oats in four crops. The actual losses may vary from year to year depending on climatic conditions.

Wild oats per ft ²	percentage yield loss wild oats and crop emerged at the same time				Time of emergence* factor (+/-)
	Barley	Wheat	Canola	Flax	
0.5	5	8	7	14	0.5
1	8	11	10	20	1
2	11	16	15	28	1
3	13	19	18	34	2
5	17	25	24	44	2
8	21	32	30	56	2.5
10	24	35	33	62	2.5
15	29	43	41	75	3
20	34	50	47	88	3

*The time of emergence information was developed experimentally for barley and wheat only. However, it may also be accurate for canola and flax. Add or subtract the appropriate number for every day wild oats emerge before or after the crop. For example, if wild oats at 2 plants per square foot emerge 3 days before barley, the yield loss changes from 11 to 14 per cent.

Management Strategy

- Prevent seed production.
- Encourage germination of existing seed reserves.

Control Mechanisms

Preventing seed set of wild oats in annual crops is very difficult unless the crop is taken off early for greenfeed or silage. Therefore, a combination of cultural and chemical control methods are needed to attack a wild oat problem.

Tillage

Summer fallow - Summer fallow increases the number of seeds that break dormancy. A new stand of wild oats will emerge after each tillage operation. Summer fallow can be grazed to control wild oats. Seed fall crops in the same year as the fallow to provide competition against wild oats that germinate in the spring.

Pre-seeding tillage - Till as early as possible after spring thaw. This warms and aerates the soil and stimulates early germination of wild oats. Early tillage of heavy, wet soils is particularly important.

Tillage prior to seeding should be done before weeds reach the three-leaf stage. This minimizes the moisture and nutrients they use. Tillage should be to a depth of 2.5 to 5 cm during warm, dry weather so the wild oats cannot re-establish.

Post-seeding tillage - Post-seeding tillage is valuable because wild oats that emerge before the crop are more competitive than those that emerge with or after the crop. Till before crop emergence to prevent any crop damage. A shallow cultivation with a rod-weeder or harrows will eliminate wild oat seedlings.

Fall tillage - Fall tillage is useful if wild oat seeds have been exposed to two or three weeks of warm, dry weather. A shallow tillage will lightly cover wild oat seeds and promote early germination in the spring. A cultivator is more suitable than a disc or harrow. If fall weather is cool and moist, avoid tillage so that dormant wild oat seeds remain on the surface exposed to the elements.

Mowing

When an infestation of wild oats is moderate to heavy, and the crop is of low density, mowing is an effective preventive measure. Wild oats should be mowed at the shot-blade stage. Early mowing can result in wild oat regrowth and seeds can still be produced.

Mowed wild oats can be used for greenfeed or, if some of the seeds have set, for silage. The fermentation process will destroy wild oat seed viability.

Rotation

Fall-seeded crops emerge early the next spring and can smother the emerging wild oats. Fall rye is generally more vigorous and competitive than winter wheat.

Land seeded to perennial forage for three or more years can provide good control for heavy infestations of wild oats. However, some wild oat seeds can survive under sod and germinate when the sod is broken.

A green-feed crop such as oats can be seeded early to enable a competitive advantage over the wild oats. To prevent weed seed production, cut the crop before the panicles of wild oats start to emerge from the sheath. Silage effectively destroys any seeds produced.

Use annual crops in the rotation, especially the more competitive crops so that yield losses are minimized and the wild oats are suppressed. In descending order, barley, canola and wheat are the most competitive small grains.

Delayed seeding

Delay seeding to allow time for wild oat seedlings to be

destroyed by tillage before or at seeding. Seed an early maturing crop such as barley. Yields may be reduced if seeding is delayed by more than 10 to 14 days.

Fertilization

Nitrogen fertilizers broadcast in the early spring can stimulate wild oat emergence. This can enable more complete control prior to seeding. Phosphorous fertilizer drilled in with the seed promotes more vigorous crop growth that helps to smother wild oat plants and reduce wild oat seed production.

Phosphorous fertilizer placement	Seed yield (bu/ac)	
	Barley	Wild oats
Control - no fertilizer	33	12
Drilled with barley	62	5

Chemical control

Several herbicides are available for control of wild oats in the various crops. Both pre-emergent and post-emergent herbicides can be used.

Refer to *Crop Protection with Chemicals*, Alberta Agriculture, Food and Rural Development, Agdex 606-1 for the most suitable herbicide.

Multi-technique Approach

Like most other weeds, successful control of wild oats will require a combination of tillage, crop rotation and chemical control. Each situation has to be evaluated and the appropriate control method(s) taken.

Biology

Understanding how insects live will help you make sound, economical pest control decisions. Although insect biology is an extensive subject, a few words on this matter now will help you to anticipate insect problems.

Insect development is classified as either complete or gradual (incomplete). Insects progress through a series of growth stages during development. Insects that have complete development proceed through distinctly different growth stages; those that have gradual development proceed through growth stages in which the young look very similar to the adult. Of these two groups, insects with complete development have biological traits that make them the more numerous group of pest species.

Insects with complete development hatch from the egg stage into the feeding and growing larval stage. Upon completion of growth, the larva changes to a resting stage called the pupa (frequently called cocoon). During the pupal stage, the insect is transformed into the adult. The adult is the reproductive and normally mobile stage of the insect's life cycle. This group of insects includes many orders of species commonly found in crops such as the beetles, flies, moths and butterflies. Most often it is the larvae of these insects, known by various common names such as caterpillars, maggots and grubs, that damage crops.

Insects with gradual development also arise from eggs. However, unlike insects with complete development, these insects go through a series of growth stages called nymphs before becoming adults. Nymphs and adults look very similar, except that the adults are larger and may have wings. There is no resting stage (pupa) in this group; the mature nymph becomes the reproductive adult after shedding its skin for the last time.

Adults and larvae of insects with complete development often consume different food. Thus, although cutworms are foliage or stem feeders, the moths consume only flower nectar or other such fluids. Many adult flies eat only nectar and pollen while the maggots may be predators (aphid-eating larvae of syrphid flies), saprophages, maggots of fruit flies in rotting fruit) or plant eaters (root maggots in canola).

Nymphs of insects with gradual development, such as grasshoppers, aphids and thrips, generally feed on the same food as the adult forms.

Information on where insects are found at different times of the year is helpful when you try to anticipate a pest problem. By uncovering grasshopper eggs laid along roadsides or other favored spots, you can judge the potential abundance of these insects prior to planting. Because each pest's biology is different, consult a handbook such as *Insect Pests of the Prairies*, University of Alberta

Press, 1989 to become familiar with the appearance of adult and immature insects and their habits.

Assess the Potential for Insect Damage

Know your pest

Insect control may be necessary in one circumstance and not in another, depending upon the impact of such natural insect mortality factors as weather, food availability and natural enemies. You should know something about the insect's biology including its habits, food needs, food preferences, reproductive cycle and habitat requirements. Find out if an economic threshold is available for an insect-crop problem. Determine under what circumstances populations will remain below economic levels. Also, estimate how many insects are necessary to cause economic damage. A large number of moths does not necessarily mean that there will be a large number of caterpillars. Insects require certain conditions to multiply or to cause damage. A good food source for the larvae and good weather conditions are always necessary. Survival of each life stage (egg, larva, pupa and adult) will be influenced by factors such as weather, diseases, predators and food supply.

Know your allies

You may find predators and parasites of pests during field scouting. You may also see dead or diseased insects infected with viruses, fungi or other pathogens. These are signs of natural pest control. If you know the enemies of your pest, you may be able to judge whether they will contribute significantly to killing off the pest so that you don't have to. You may also be able to avoid harming beneficial insects during pest control.

Know the economic threshold

Economic threshold is an important concept of integrated pest management (IPM). This is the pest density at which control measures should be started to prevent an increasing pest population from causing economic injury. This density may be the number of pests per plant, pests per square metre, pests per sweep of an insect net or some other suitable measure.

The percentage of plants damaged is sometimes used when pests develop inside plants, when pests are difficult to see or sweep because of dense or tough foliage, or as an additional piece of information to complement other measures of pest density. Several sampling methods may be required to monitor pest numbers because no single method is suitable for all species nor for the whole growing season (See Field Scouting). Many economic thresholds currently in use are estimates that are not fully supported by research. Some economic thresholds have been developed for major pests of crops in Western Canada.

When pest density or damage reaches the economic

Economic thresholds for insects attacking cereals and corn of the Canadian Prairies

Insect	Economic threshold	Notes on managing infestations
Aphids		Do not treat aphid infestations when cereals beyond the soft dough stage. Aphid populations decrease rapidly as heads mature. Birdcherry-oataphid and greenbug can vector barley yellow dwarf virus. Greenbug injects a toxin which stunts plants.
Greenbug	Seedling: 5-15; Boot: 10-25 (aphids/stem)	
Birdcherry-oat	Seedling: 20; Boot: 30 (aphids/stem)	
Corn leaf	Seedling: 20; Boot: 30 (aphids/stem)	
English grain	Seedling: 30; Boot: 50 (aphids/stem)	
Russian wheat	Winter cereals: Seedling: 15-20% after October 1st; Spring cereals: Seedling: 10-15%; Boot: 15-20% (% plants infested).	
Armyworm	More than 10/m ² .	
Barley thrips	Mean of 7.5 thrips/stem (based on a sample size of 50 stems, chemical control = \$5.75/acre and market value = \$1.90/bushel)	Infestations of one thrips/stem have resulted in a 1.25 bushel/acre loss in one instance and a 0.4 bushel/acre loss in another.
Cutworms		8.4 PWC larvae/m ² caused 25% loss in wheat; 30 PWC larvae/m ² caused 100% yield loss. PWC & RBC: Well established crops with good moisture can tolerate higher numbers.
Pale western	3-4/m ² .	
Redbacked	5-6/m ² .	
Army cutworm	1-2/30 cm of row for plants less than 30 cm tall; 4/30 cm of row for plants 12-15 cm tall having adequate moisture.	
European corn borer	Dryland grain corn: Economic loss will occur when 50% of plants show leaf feeding (shot-holing).	
Grain stink bug	Wheat: 1/head caused losses greater than 30%.	
Grasshoppers	Control required when hoppers number 13 or more/m ² in fields or 25 or more/m ² in roadsides.	Control may be required when hoppers number 7-12/m ² in fields or 13-24/m ² in roadsides.
Hessian fly	None available.	Death of individual wheat or barley tillers or of the entire plant may result if more than several larvae are present per plant.
Orange wheat blossom midge	1/5 heads of wheat.	Infestations of 30, 60 and 90% reduced spring wheat yields by 40, 65 and 80% respectively.
Wheat stem sawfly	None available.	Resistant varieties are required if 10 - 15% of the previous crop was cut by sawfly. Infested stems of wheat averaged 17% yield loss.

Economic thresholds for insects attacking oilseed crops on the Canadian Prairies

Insect	Economic Threshold	Notes on Managing Infestations
Aphids	Flax: 8-10 aphids/stem at green bell stage Canola: rarely a problem.	
Army cutworm	Seedling mustard: less than 5/m ² .	
Bertha armyworm	20 larvae/m ² consume the equivalent of 65 kg canola seed/ha (1.16 bu/ac).	Economic threshold may not apply to Polish type canola.
Diamondback moth	Control not required in canola until larvae exceed 200-300/m ² .	Threshold may be lower for Polish than for Argentine type canola.
Flea beetles	Control required if 50% leaf tissue consumed; less if growing and moisture conditions are poor.	
Sunflower beetle	Control required with 1 adult/2-3 seedlings or over 10 larvae/plant.	Severe leaf damage may occur to plants in the 2-6 leaf stage when adults are numerous, or at any time when larvae are numerous.
Sunflower maggots	None established.	
Sunflower midge	Losses are more severe around field edges. Losses can be estimated by sampling heads and classifying them on the basis of the degree of head distortion.	Seed destruction and head distortion can cause serious losses in the Red River Valley of Manitoba.
Sunflower seed weevils (red & grey)	Oil sunflower: 10-12 seed weevil adults/head. Confectionery sunflower: One adult/head.	Apply treatment at early anthesis when 30-70% of sunflower heads are in early pollen formation (R-5.1 stage). For example, treat when 30-70% of plants show ray petals and at least one row of disc flowers. Reinfestation may occur in areas with a high weevil population. Fields should be rechecked when 80-100% of heads are at the R-5.5 stage.

Economic thresholds for insects attacking forage and special crops on the Canadian Prairies

Insect	Economic Threshold	Notes on Managing Infestations
Alfalfa weevil	<p>Alfalfa hay crops: 20-30 larvae/sweep will result in a 12% leaf loss; 50-75 larvae/sweep will result in a 30% leaf loss. At peak larval populations, 56 larvae/stem will return treatment costs.</p> <p>Alfalfa seed crops: 20-25 larvae/90° sweep or when 35-50% of foliage tips show damage.</p>	Alfalfa hay crops: Apply controls when 25-50% of leaves on upper one-third of stem show damage or when 50-70% of terminals show injury.
Aphids Pea aphid	<p>Canary Grass: More than 50 per head between heading and soft dough.</p> <p>Field Peas: Usually from 1-4 aphids/20 cm stem tip when 50-75% of plants have begun to flower.</p> <p>Alfalfa: 75-100 aphids/plants.</p>	In one study, 1430 aphids/sweep did not reduce the yield of alfalfa. In another, caged alfalfa initially infested with 100-200 aphids/plant produced less forage and had lower carotene content than uninfested plants.
Beet leafminer	Sugar beet: Only infestations causing more than 25% defoliation require treatment.	
Grasshoppers	Alfalfa: See Cereals and Corn table. Safflower: More than 15/m ² .	
Plant bugs Lygus Plagiognathus Superb	Alfalfa seed; 5 nymphs/sweep (any or all species of plant bugs) when alfalfa is in bud or bloom.	
Sweetclover weevil	<p>Seedling crop (cotyledon stage): 1 weevil/5 seedlings under slow growing conditions or 1 weevil/3 seedlings under normal growing conditions.</p> <p>Newly emerged 2nd-year sweetclover: 9-12 weevils/plant.</p>	
Red clover thrips	Red clover seed fields: Damage insignificant unless 50-80 thrips/raceme are present.	Threshold levels have occurred only during years of early spring drought on dryland.

threshold, control measures should be taken. Using the economic threshold as a guide eliminates unnecessary measures that increase costs of crop production, interfere with natural control of the pest, and may add to environmental pollution.

Know the economic injury level

A related concept, which determines the economic threshold, is the economic injury level (EIL). EIL is the lowest pest density that causes damage equal to the cost of control measures. Several factors determine the EIL: crop response to injury, consumer demand for unblemished produce, crop market value, control costs, and the type of pest damage. Some of these factors are relatively simple to estimate; others are difficult because they depend on complex biological processes about which little is known.

An important principle of integrated pest management is that the presence of a pest in a crop does not mean economic damage will follow. Plants usually compensate for injury caused by small numbers of pests and in some cases yields may even increase. Because plants compete with each other for light, moisture and nutrition, the loss of some plants to insects can cause neighboring plants to produce more. In such cases, small numbers of insects will not reduce overall yield. Insects may also have a pruning effect on plants that suppresses the growth of one plant part and increases the weight of others. For example, small infestations of the bean aphid decrease tip growth of the bean plant and increase yields. No damage occurs if small numbers of a pest attack leaves or roots that are providing more nutrients than the harvestable parts of the plant can use. Flea beetles can destroy up to 50 per cent of the leaf area of canola seedlings without affecting yield.

Know the population dynamics of pest insects

The population dynamics of most pest insects follow a cycle of abundance (outbreak) and relative scarcity. Outbreaks do not last forever. Outbreaks are usually followed by the eventual reduction in pest numbers. Some pest insects, however, may not show a cycle in abundance: flea beetles in Manitoba have been abundant since the early 1970s and are usually a significant problem there.

An insect's habitat can maintain only a specific number of insects. The concept of carrying capacity is based on the principle that reproduction and survival change with population density. Without the limits of carrying capacity, insect numbers would increase exponentially. The exponential curve in the following figure shows how population density would increase. Producers in Alberta will be familiar with the concept of carrying capacity as it applies to pasture and cattle.

At low population levels, species reproduce as though resources were unlimited. Many offspring are produced and mortality is low. At high population levels, fewer resources are available, leading to a higher death rate and lower birth rates. Fewer eggs are laid because of competition for available egg laying sites and food. Populations stop increasing when the insect population reaches the carrying capacity of the habitat. Population growth restrained by the habitat's carrying capacity is shown by the S-shaped curve. Growth starts slowly, increases rapidly, and then stabilizes near the carrying capacity, providing no catastrophes occur such as excess rain or extreme temperatures.

In the real world, factors such as food, breeding sites, space, time, weather, parasites, predators and pathogens as well as man's intervention combine to limit population growth. The following table shows how such factors influence the mortality rate of bertha armyworm.

Mortality of bertha armyworm

Life stage	Cause of mortality	Per cent mortality	Cumulative survival (%)
Egg	Weather, predators diseases	14	86
Early to mid larva	Weather, predators diseases	18	71
Late larva	Physiological, at pupation	12	16
	Parasites	62	
	Diseases	4	
	SUBTOTAL	78	
Pupa	Physiological	12	7
	Cultivation injury	14	
	Low temperature	27	
	SUBTOTAL	53	
Adult	Unable to emerge from soil	50	3.5

The chief natural enemy of the bertha armyworm is a parasitic wasp whose larva lives inside the caterpillar but does not kill it until the caterpillar is nearly full grown. Notice that parasites destroyed 62 per cent of late-stage larvae. Sixteen per cent of the original population survived to pupate. Of this remaining 16 per cent, 12 per cent died of "unknown" causes, 14 per cent died from injuries suffered during tillage and 27 per cent from winter cold. Only 3.5 per cent survived to the adult stage, but this was probably enough to allow for a population increase in the next generation. Clearly, a small change in the effect of any mortality factor can make a significant difference in the number of survivors.

Farmers get a lot of help from natural mortality. By seeding early or using some other cultural control you can further reduce the survival rate of bertha armyworm.

Natural mortality often reduces the population below the economic threshold. Populations have an average equilibrium position despite the temporary interventions of pest control. The following figures show examples of how population fluctuations can be related to economic levels.

Many insect species feed on cultivated crops without ever reaching densities high enough to cause economic injury. Consequently, they are rarely noticed. Examples include alfalfa caterpillar on alfalfa, club-horned grasshopper on range land and cabbage aphid on canola.

Cabbage aphid on canola

Other insects are occasional pests that exceed economic injury levels only when their population densities increase because of unusually favorable weather. Examples include forest pests such as fall webworm that becomes epidemic in 5 to 10 year cycles, alfalfa looper on canola, and grasshoppers on cereals. When their populations peak, pests of this type require some sort of intervention, usually chemical, to reduce their numbers to tolerable levels.

Grasshoppers on wheat

Insects with economic injury levels only slightly above the equilibrium population are perennial pests, and include: gypsy moth in hardwood forests in eastern Canada, grasshoppers on cereals in the driest grain-producing areas of Alberta, and Colorado potato beetle on potatoes. With these pests, even small population increases can cause damage. The general practice is to intervene with chemical or other control agents whenever necessary to reduce the population below the economic injury level.

Codling moth on apples

Insects that have economic injury levels below the equilibrium position are severe pests. Examples include codling moth on apple and European corn borer on fresh market sweet corn. Regular and constant intervention is required to produce marketable crops when pests of this group are present. Another example is western flower thrips on cucumber in greenhouses. Very low population densities of this insect can cause extensive damage to budding florets. A complication in the control of thrips arose when resistance to commonly used insecticides became apparent. An integrated program is now being developed that uses regular releases of a predatory mite, *Amblyseius cucumeris*.

Colorado potato beetle on potatoes

ALFALFA LOOPER

Autographa californica

Insect Life Cycle

Host plants

Although considered general feeders, alfalfa loopers prefer alfalfa, clover and lettuce. Other hosts include canola, peas, spinach and various garden crops, ornamental trees and tree fruits. Damage to canola occurs sporadically in northern and southern Alberta.

Overwintering

Found throughout Alberta, alfalfa loopers may overwinter in the pupal stage. However, most of the Alberta population is blown in from the United States each year.

Spring appearance

Early summer moths are likely to be migrants from the United States. The moths appear all summer long because generations overlap. Moths feed on flower nectar at dusk and fly during daylight hours.

Number of generations

There are two or three generations per year.

Natural enemies

Pathogens - A virus disease will usually control late-season infestations.

Damage Assessment

Damage description

Alfalfa loopers are an occasional pest in Alberta. Larvae are present from mid June through September. Small larvae feed on leaf surfaces and medium-sized larvae eat ragged holes through leaves. Older larvae feed along leaf margins

and may defoliate a large portion of the plant as well as clip flowers and seed pods. The actual decrease in yield that results from this feeding damage is not known. Compensation by plants for such injuries may include continued or additional stooling. The plants may also have more flowers and set more and larger seed. Flower clipping is the most significant problem in canola, but the plant can normally compensate unless severe damage occurs.

Sampling methods

Beat plants in an area 50 cm x 50 cm and record the number of larvae on the ground. Repeat this procedure several times in different locations to obtain an average number of larvae per square metre for the field.

Economic threshold

Damage occurs through defoliation and clipping of flowers and immature seed pods. No economic threshold has been established. However, more than 15 larvae per square metre, combined with heavy defoliation or flower and pod clipping, may warrant control.

Management Strategy

Cultural practices

Avoid growing canola near alfalfa.

Biological control

If an infestation occurs, assess the damage to plants and sample the field to determine the numbers of larvae. Delay an insecticide application as long as possible to allow diseases to control the pest. Historically, the pest has been adequately controlled by viral diseases.

ALFALFA WEEVIL

Hypera postica

Insect Life Cycle

Host plants

Alfalfa is the main crop injured by alfalfa weevils, but they may feed on clovers, sweetclover and vetches.

Overwintering

Adults overwinter in protected areas, often outside of fields, including windbreaks, wooded areas and under debris along fence lines. They may also survive under trash in fields or in

the crowns of alfalfa. Severe winters may cause high mortality and cold springs may prevent egg production.

Spring appearance

In the spring after alfalfa has started to grow, adults take flight in search of food plants and sites to lay eggs. Females chew holes in stems, insert the tips of their abdomens into the holes and lay a cluster of eggs in each hole.

Number of generations

There is one generation per year.

Natural enemies

Parasites - Seven to ten insects parasitize the alfalfa weevil in Alberta, including a small wasp, *Bathyplectes curculionis*, which may parasitize up to 25 per cent of an alfalfa weevil population in southern Alberta.

Predators - A predatory wasp recently discovered in southern Alberta may be beneficial in alfalfa seed fields. Damsel bugs feed on the weevil larvae.

Damage Assessment

Economic importance

Larvae feed on the growing tips of plants and later on leaves where they eat all but the main veins. They can destroy whole fields when sufficiently abundant. Damaged fields appear as if they were suffering from frost injury.

Damage description

Larvae and adults of this weevil feed on alfalfa. In spring, adults emerge from winter hibernation to feed on new shoots. Most damage to alfalfa fields is done in late spring and summer by the larvae, which feed inside leaf buds at the tips of stems and later attack the leaves. In a heavy infestation, the leaves are so badly shredded that the field takes on a frosted appearance.

Adults cause scars on shoots by feeding and leave puncture holes in shoots during egg-laying. These punctures are visible and indicate the level of egg-laying activity. Newly hatched larvae feed for three or four days inside the stem before moving up the plant to feed on developing leaf buds. Young larvae severely damage shoot tips by feeding within the folded leaves, but the damage is not readily seen. Older larvae feed on open leaves and skeletonize them, leaving only veins and stems. Defoliation is most severe toward the terminals, giving the field a grayish or frosted appearance. Leaves notched at the edges are characteristic of damage by weevil adults.

Damage is most severe to first-cut alfalfa, but damage to second-cut alfalfa also occurs when the insect has been present for a number of years. After the first hay crop is cut, larvae drop into the stubble and concentrate under the windrow for protection. While under the windrow, they feed on buds of the alfalfa crowns, retarding growth of the second crop.

Alfalfa weevil infestation can reduce hay yield by 50 per cent; the quality of hay is also reduced. Feeding damage may greatly reduce yields of seed fields.

Sampling methods

Early in the season, field inspections to determine the size of the weevil population and their stage of development are the first steps of a successful control program. The number of weevils or egg punctures indicate the pest's presence and expected damage.

To determine the number of weevils later in the season, sample the top 20 cm of the crop with a sweep net. Take sweeps in different parts of the fields. Calculate the average number of adults per sweep.

Economic threshold

Alfalfa hay crops - 20-30 larvae/sweep can cause a 12 per cent leaf loss; 50-75 larvae/sweep can cause a 30 per cent leaf loss; damage caused by 46 larvae/stem at the peak of larval population will offset the cost of treatment at that time. Alternative thresholds for alfalfa hay crops are to apply controls when 25 - 50 per cent of leaves on the upper one-third of the stem show damage or when 50 - 70 per cent of terminals show injury.

Treat alfalfa seed crops when there are 20-25 larvae/90° sweep or when 35-50 per cent of foliage tips show damage.

Management Strategy

Cultural practices

Early harvest of first growth alfalfa (late bud to first bloom) when larvae are present will reduce populations of new adults, but this is not always practical. Production of green chop instead of dry hay can result in seasonal reductions of about 50 per cent in total numbers of weevils. However, the stubble should be checked for signs of re-growth three to five days after the alfalfa is cut. If green-up does not occur, determine the cause of the problem. A stubble treatment of insecticide may be necessary to control surviving larvae.

Proper soil fertility will promote more vigorous stands and lessen the effect of larval feeding.

Biological control

In Alberta, this weevil is attacked by a parasitic wasp that was introduced into the United States as part of a biological control program.

ARMY CUTWORM

Euxoa auxiliaris

Insect Life Cycle

Host plants

Army cutworm larvae eat the foliage of wheat, oats, barley, mustard, flax, alfalfa, sweetclover, peas, cabbage, sugar beet, various weeds (notably stinkweed) and grasses.

Overwintering

The female moths each lay about 1,000 eggs in soft soil in late August through October. The eggs hatch in a few days to two weeks. The larvae feed above ground on plant foliage at night and remain below ground during the day.

Development stops when the ground freezes; larvae are usually about half-grown by this time. They remain inactive throughout the winter just beneath the surface in loose soil.

Appearance times

Larvae begin to feed in April and continue to feed until pupation in May to early June. Moths appear in June for a brief flight period, aestivate (summer hibernation) in buildings and under trash and clods during June and July, and then become active again for the egg-laying period.

Number of generations

There is one generation per year.

Natural enemies

Five or possibly six species of wasp parasites have been recorded for army cutworm in Canada, mostly from Alberta.

Copidosoma is a tiny parasitic wasp (about 2 mm in length) which lays a single egg in cutworm larvae. The egg produces multiple embryos from which over a thousand offspring may be produced. Sixty per cent or more of army cutworm larvae were parasitized by this organism during an outbreak in Alberta in 1990. *Copidosoma* prolonged the larval stage of army cutworm into June; the cutworms caused damage to spring crops, an unusual circumstance since they normally have pupated by that time.

Damage Assessment

Damage description

Damage can be of any severity up to complete defoliation. In severe infestations, the area defoliated has ranged from an individual field to thousands of acres with larval densities of up to 200 per square metre. The first signs of damage are holes in leaves and semi-circular notches eaten from the edges of leaves.

Sampling and monitoring methods

Army cutworm moths have been monitored in southern Alberta with pheromone traps since 1978. Sample larvae as for other subterranean cutworm species. Mark an area of soil 50 cm by 50 cm. During the day, larvae should be within the top 5-7 cm of soil surface. Count the larvae within each 50 cm of row in the sample area. Multiply the number of larvae by four to give the number of larvae per square metre. Repeat the process in different areas of the field.

Economic thresholds

Economic thresholds for this insect have not been rigorously tested. However, the following guidelines may be helpful.

The economic threshold is dependent, among other factors, on the crop infested. Mustard is more susceptible to damage from this cutworm than are cereals and alfalfa. A density of five cutworms per square metre is sufficient to destroy a mustard field, whereas cereals and alfalfa can withstand cutworm populations of up to 50 per square metre. The latter crops can resume growth after attack whereas mustard cannot.

Other factors affecting the economic threshold are the plants' growth condition and the number of weed hosts in the field. A weedy field will suffer less damage than a clean one. Forage crops and pastures must be watched closely in April and early May for the presence of these larvae. Plants that have adequate moisture and are vigorously growing with 12 to 15 cm of top growth can withstand four larvae per 30 cm of row without loss of yield. If plants are under 10 cm in height and two or more larvae per 30 cm of row are present, chemical treatment is required.

Management Strategy

Effects of weather

Each outbreak year is usually preceded by a year with an abnormally dry July and wet autumn. A July with less than 3.8 cm of rainfall and a mean temperature of 17°C or higher is favorable to a population increase. However, an outbreak may not occur in the following year unless a dry July is followed by a total of over

11.4 cm of precipitation in August to October, with most of it in September. Army cutworms are reduced in a wet July when moths are drowned or covered with mud during aestivation. A dry fall delays egg-hatching by up to two months; eggs and first instar larvae are very susceptible to desiccation and are killed in the soil. Because of these mortality factors, an abundance of moths in early fall does not necessarily mean a cutworm outbreak the following year.

Cultural practices

Spring crops can escape damage if they emerge after the cutworms have pupated. This is the usual situation and occurs when cutworm development is advanced by favorable fall or spring weather or crop seeding is delayed by wet weather. Crops can also be seeded later in the season to avoid attack by this pest.

Mechanical

If cutworms are marching, plow a steep-sided trench across the path of advance. Line the trench with a plastic sheet to ensure that larvae will not climb out of the trap. Use of insecticides on larvae in this limited space is economical.

BEET WEBWORM

Loxostege sticticalis

Insect Life Cycle

Host plants

The beet webworm attacks a wide range of broad-leaved field and garden crops. These include sugar beets, canola, flax, sunflowers, alfalfa, mustard, cabbage, carrots, beets, lettuce, onions, potatoes and asparagus. Lamb's-quarters and Russian thistle are also host plants. The larvae rarely attack cereals, although they can cause alarm to producers by marching through cereals in search of more suitable foods. This insect is found throughout Canada but is most common on the Prairies.

Overwintering

These insects overwinter as mature larvae in silk-lined cells in the soil. They pupate in these cells in late spring.

Appearance times

Moths from the generation that overwinters appear in late May, June or early July. They are night-active moths but if disturbed will fly readily from their daytime hiding places. Female moths lay eggs on the underside of plant leaves. Larvae appear in June and July, and adults emerge in July and August. Larvae of this second generation are active in August and September. They prepare for winter as full-grown larvae.

Number of generations

There are two generations per year.

Natural enemies

Parasites - The webworm is attacked by several species of parasitic insects, which reduce the numbers of second generation moths. The soil in which cocoons are placed can influence the degree of attack by one species of parasite. Cocoons in sandy soil are more frequently parasitized than those in heavy clay, because they are more frequently exposed by wind and rain and more readily penetrated by the parasite's ovipositor. The importance of natural enemies in the population dynamics of the beetworm is uncertain; direct effects of weather are probably more important.

Predators - Franklin's gulls and crows feed on beet webworms.

Damage Assessment

Economic importance

Beet webworm causes economic damage somewhere on the Prairies almost every year. In any one area, however, it is a sporadic pest.

Damage description

Beet webworm is primarily a pest of canola, flax and sugar beet. On hatching, beet webworm larvae eat holes on the underside of leaves. Eventually, only the heavy veins remain.

Larvae can quickly eat the leaves of canola and may then chew into seed pods or strip surface tissue from pods or stems. This gives the crop a whitish appearance. Crops with light infestations may suffer reduced yields from pod peeling. On flax, larvae eat leaves, flowers and patches of bark from the stem but rarely chew into green immature pods. On sugar beets, young webworms feed on the underside of leaves. Older webworms eat holes through leaves and sometimes leave only ragged veins. From a distance, a heavily infested sugar beet field looks slightly brown and has a feathery appearance.

Damage often occurs to crops when starving larvae march from adjacent weedy fields or from other infested fields that have been harvested, mowed or sprayed with herbicide to control weed hosts. The most serious damage to crops is caused by larvae of the first generation.

Sampling methods

For canola and most other host crops, beat the plants in an area 50 cm x 50 cm and count the larvae knocked to the soil. Repeat the process three more times short distances away to obtain a total number per square metre. Sample different parts of the field to obtain an average number per square metre. For sugar beets, count the number of webworms per leaf.

Economic threshold

Economic thresholds on canola may be similar to those for bertha armyworms. On sugar beets, take control measures when counts of webworms reach one or two per sugar beet leaf on more than half the leaves.

Management Strategy

Effects of weather

In general, years in which beet webworms are most important as a pest have relatively dry, hot summer weather. The weather affects beet webworm's importance as a pest; as weeds dry up, the larvae march and frequently attack adjacent crops. Larvae destroy foliage more rapidly in hot weather. In some drought years, however, weeds may dry up so quickly that larvae die from starvation.

Cultural practices

To reduce the likelihood of infestation, keep fields and gardens free of weeds.

Check sugar beets, canola and flax for eggs and young larvae if moths are observed in the field. Large flights of moths are not always followed by high numbers of webworms.

Biological control

Although parasites help keep the webworm under control, only the use of insecticides will satisfactorily control the problem when a field is heavily infested.

BERTHA ARMYWORM

Mamestra configurata

Insect Life Cycle

Host plants

Bertha armyworms are a pest of canola on the Prairies. They also attack a large number of other plants including turnips, potatoes, alfalfa, sweetclover, beans, peas, tomatoes, garden vegetables and various flowers. However, crops other than canola are generally a less preferred food source for the larvae. Damage on these plants occurs only after the large larvae have defoliated suitable food plants such as lamb's-quarters. They do not feed on cereal crops.

Overwintering

Bertha armyworms overwinter as pupae in the soil.

Spring appearance

Moths emerge from pupae that overwinter. The flight period generally extends from mid June through July in southern and central Alberta and is somewhat later in the Peace River district.

Number of generations

There is one generation per year.

Natural enemies

Predators - Various birds, small mammals and insect predators feed on pupae that are exposed during fall or spring tillage.

Parasites - The two main parasites of bertha armyworms are the ichneumon wasp, *Banchus flavescens*, and the tachinid fly, *Athrycia cinerea*. These parasites overwinter in the soil within the pupal case of their host.

Insect parasites may kill up to 75 per cent of the armyworms. Unfortunately, larvae are often not killed until after they have damaged the host crop. Nuclear polyhedrosis virus, another natural enemy of bertha armyworm, kills many larvae when insect populations are high as will fungal pathogens if the weather is suitable.

Damage Assessment

Economic importance

Bertha armyworms are a perennial pest of canola. Minor infestations have occurred ever since canola was first planted on the Prairies. In 1971 through to 1973, a severe outbreak

occurred and a total of 1.75 million acres of canola were sprayed to control bertha armyworms.

Damage description

Larvae chew irregularly shaped holes in canola foliage, but the main damage is caused when older larvae reduce seed yield as they chew into pods. In bertha armyworm outbreaks, up to a quarter of the pods in individual fields may be destroyed. A larval population of about 200 per square metre can reduce seed production by one half. A population of 20 larvae/m² consumes about 1.1 bu/ac.

Larvae can feed on leaves and harm flax. However, the chief damage results when bolls or stems below the bolls are chewed so that they fall to the ground. Damage to flax and crop hosts other than canola does not normally occur until larvae have consumed the cruciferous weeds in the field.

Damage to unsuitable host plants occurs in weedy fields during years of high bertha numbers. Average defoliation of potato in outbreaks has been over 10 per cent. On tomato, up to 10 per cent of the fruit has been destroyed. On cabbage, larvae eat the foliage and bore into heads and in some years and places have caused more damage than imported cabbageworm. Damage to sweetclover is primarily to flowers and seeds, and in one instance resulted in a total loss of the seed in over at least 1,500 acres.

Monitoring methods

In 1985, Alberta, in co-operation with Agriculture Canada's Lethbridge Research Station, established a province-wide monitoring program for bertha armyworms and other noctuid (cutworm) species. Information on moth numbers is available from some district agriculturist's offices.

Moths can be on the wing at any time during June and July but late June to mid July is the most likely time. The best time to set out traps will depend on spring weather and trap location. Traps are commercially available. Monitor the moth flight in your location by putting traps out from June 20 to July 20. Keeping records of numbers of moths trapped will allow timely and accurate management decisions.

Sampling methods and economic thresholds

A decision to sample larvae may result from inspections of the field or records of pheromone trap catches. In either case, larvae should be sampled by mid July. The bulk of

the larval population will not have moved into the fifth and sixth larval stages at that time. An early decision to spray allows ample time to prepare. It is unlikely that natural enemies will intervene at this stage to prevent damage. Bertha armyworm larvae have several parasites and diseases but they do not kill the larvae until growth is complete or nearly so.

Economic thresholds for bertha armyworm in canola (larvae/m²)

Cost of spray per bushel: (\$ / ac)	Value of seed to producer (\$ / bu)						
	6	7	8	9	10	11	12
9	26	22	19	17	16	14	13
10	29	25	22	19	17	16	14
11	32	27	24	21	19	17	16
12	34	30	26	23	21	19	17

Values are based on an average of 20 larvae/m² consuming the equivalent of 65 kg canola seed/ha (1.16 bu/ac).

Step 1 - Before taking samples, determine the economic threshold for your particular situation from the table above. If you can get \$9 per bushel for your crop and spraying will cost \$10 per acre then 19 or more larvae per square metre will lead to an unacceptable crop loss.

Step 2 - Sample the field for armyworms. Take three 1 m² samples, spaced at least 50 paces apart and at least 50 paces inside the field. The best way to count larvae is as follows: Shake the plants vigorously so that larvae fall into the sampling area, then count the larvae on the ground. Make sure to look beneath leaf litter and clumps of dirt. If you use the 50 cm x 50 cm sampling frame, multiply the number of larvae by four and record the numbers per m². Calculate an average number per m².

Step 3 - Calculate the total number of armyworms for the three 1 m² samples.

Step 4 - Use the following decision table to determine if control is needed.

- Determine the range in which your economic threshold lies (Column A) from Step 1.
- Read across from the total number of samples taken (Column B).
- Find the column in which your total number of armyworms sampled lies (the total from Step 3). If your sample total lies in Column C, you have no problem. If your sample total lies in Column D, you must take three more samples.
- Add together the numbers of all armyworms sampled (for example, from samples 1, 2 and 3 plus samples 4, 5 and 6) and so on. If a decision still cannot be made after nine samples, the number of armyworms in the field is

very close to the threshold level. Under these circumstances, apply an insecticide if the crop will not be swathed for at least a week. If swathing time is closer, don't spray. If your sample total lies in Column E, your field (or the infested part of it) needs to be treated.

Decision table for bertha armyworm sampling

(A) Economic threshold (armyworms per m ²)	(B) Total number of samples	Total number of armyworms sampled		
		(C) Treatment not needed	(D) More samples needed	(E) Treatment needed
13 - 17	3		0 - 94	95 or more
	6	less than 21	21 - 159	160 or more
	9	less than 50	50 - 220	221 or more
18 - 22	3	less than 2	2 - 118	119 or more
	6	less than 37	37 - 203	204 or more
	9	less than 79	79 - 281	282 or more
23 - 27	3	less than 8	8 - 142	143 or more
	6	less than 55	55 - 245	246 or more
	9	less than 108	108 - 342	343 or more
28 - 32	3	less than 14	14 - 166	167 or more
	6	less than 73	73 - 287	288 or more
	9	less than 138	138 - 402	403 or more
33 - 37	3	less than 24	24 - 186	187 or more
	6	less than 96	96 - 324	325 or more
	9	less than 175	175 - 455	456 or more

Management Strategy

Cultural practices

Effects of tillage and snow cover - Fall tillage reduces the numbers of bertha armyworm pupae that overwinter. Snow depth also affects overwinter mortality; mortality tends to increase when snow accumulation is light. The parasites of the pest are also affected by tillage, but to a lesser degree.

Variety selection - Infestations in Polish varieties tend to be lower than in Argentine varieties; this difference may be due to duration of bloom. Egg-laying females are most attracted to canola at early bloom. Polish cultivars have a shorter bloom period and are therefore less likely to be in this susceptible stage during the peak of moth activity.

The date to maturity depends upon the cultivar and can influence susceptibility of the crop to infestation. Thus, consider choice of cultivar along with economics, harvest time and other criteria. In Alberta, Polish varieties tend to mature about 13 days earlier than Argentine varieties and may be harvested before significant damage occurs. Maturity can vary considerably depending on location, weather and date of seeding.

Seeding date - By selecting an early maturing variety and seeding early the bertha armyworm problem can be avoided altogether unless moth flight is exceptionally early. Indeed, canola harvested before August 15 is unlikely to suffer yield loss from bertha armyworm. Mated bertha armyworm females prefer to lay eggs on canola in the early

bloom stage. Fields in this stage during the egg-laying period tend to be hardest hit. This is at least part of the reason infestations tend to be spotty even within a local area. Each

field must be inspected because the infestation level is likely to vary significantly from field to field.

CANOLA ROOT MAGGOTS

Delia spp.

Insect Life Cycle

Host plants

Root damage to canola crops in Alberta is caused mainly by the cabbage maggot, *Delia radicum*, except in north-eastern Alberta where the turnip maggot, *D. floralis*, is the more numerous species. Both species also infest other cole crops, including rutabaga, cabbage, mustard and radish.

Overwintering

During the second half of July larvae leave the roots to pupate in surrounding soil. The puparia are reddish brown in color and 6-7 mm long.

Spring appearance

In northern Alberta, adults of the cabbage maggot emerge from overwintering puparia from May 15 to July 15, with most emerging during June.

The life history of the turnip maggot in northeastern Alberta is similar, but emergence of adults from overwintering puparia does not begin until the first week of June, about two weeks later than the cabbage maggot.

Number of generations

In northern Alberta, the cabbage maggot has one generation. A few new adults emerge during the same season and no second generation of larvae is found on canola. On irrigated land in the Lethbridge area, there are two generations of cabbage maggot, with peaks of egg laying in June and again in late August to early September.

The turnip maggot has only one generation throughout its Alberta range.

Natural enemies

Predators - The most important predators of the immature stages of root maggots are larvae and adults of ground beetles and rove beetles. The most abundant species of ground beetles in canola fields in northern Alberta are *Bembidion* species, which feed on root maggot eggs. The rove beetles that are common in canola fields are probably predators of root maggots, the most abundant prey during July.

Parasites - Insect parasites attack a specific stage of the host. Parasites of the puparia of root maggots are found in Alberta, but their incidence in canola fields appears low.

They may not follow the rotation of canola crops as efficiently as does the cabbage maggot, because they attack insects other than the cabbage maggot on cole crops.

Adult flies may be infected by two species of parasitic fungi, *Entomophthora* and *Strongwellsea*. *Entomophthora* infection causes quick death. Many species of flies are susceptible to this disease. The *Strongwellsea* fungus is specific to root maggots and may achieve high rates of infection. Although infected flies are not killed, the females are unable to mature eggs.

Damage Assessment

Economic importance

While plant mortality from maggot damage alone is normally low, maggot infestation places the crop at risk of yield losses due to late-season foot rot. A mortality rate of 40 per cent occurred near Westlock in 1983 from the combined effects of maggot damage and root rot under persistently wet soil conditions.

Crop infestations of root maggot are higher in those areas of Alberta where cooler temperatures and higher moisture conditions prevail. These conditions promote maggot survival and development, and commonly occur north and west of Edmonton and in the Peace River regions. In the north-west region, nearly 100 per cent of the canola plants suffer some root damage by the end of July. In the Peace River region, plants infested with root maggots averaged 31, 15 and 25 per cent during 1981-83, respectively. In the remaining regions, an average of 5, 13 and 16 per cent of the plants in a field were infested during 1981-83, respectively. Most infested roots were scarred on the surface only. However, tunnelling throughout the roots and occasional plant death also occurred. In southern Alberta, maggots are a problem only on irrigated land.

The economic effect of maggot damage and secondary foot rot appears to vary with weather conditions. In 1989 trials of Tobin canola near Edmonton, exclusion of root maggots and consequently of foot rot increased yields about 50 per cent. During 1990 and 1991, maggot-control trials using other varieties achieved yield increases of up to 20 per cent. The determining factor seems to be the weather in late July and early August. By this time most of the roots have been infected with *Fusarium* rot fungi (foot rot) around maggot wounds. If the preharvest weather is hot and dry, further spread of the fungus will be inhibited. But if there is a period of cool, wet weather,

the rot fungi will spread throughout the roots and cause lodging and mortality.

Damage description

Maggot feeding on canola typically produces irregular vertical furrows on the main rootstock. Feeding by three or more larvae may girdle plants and interrupt the supply of water and nutrients to aerial parts. Scars caused by maggot feeding are often invaded by fungi, especially *Fusarium* (foot rot), from surrounding soil. While canola plants can resist this infection under good growing conditions or low maggot numbers, resistance may break down if wet soil conditions favorable to fungal growth prevail during July. In such cases, the plants wilt and finally break off just below ground level from the combined effects of maggot feeding and root rot.

Damage caused by larval feeding accumulates from late June to the end of July, by which time most larvae have pupated and damage for the year is more or less complete.

Monitoring methods

Adult flies can be netted or trapped in yellow bowls of water set around field margins. Their identification requires expertise because many similar species of flies are attracted to canola fields when the crop is in flower.

Sampling methods

Inspect the bases of stems and surrounding soil with a hand lens in mid to late June for eggs. Inspect rootstocks from late June through July to determine the degree of larval infestation and root damage. To avoid dislodging larvae and damaging rootlets, cut a 5 cm core of soil around the roots with a knife, lift the plant and count the

larvae on the roots while removing the soil.

A less time-consuming procedure, if only a damage assessment is needed, is simply to pull the plants while grasping the base of the stem. Brush off the soil and inspect the rootstock for scars caused by maggot feeding. The best time to assess cumulative damage for the season is the last week of July. During August, damage may be underestimated because dead plants are no longer obvious.

Sometimes it may not be apparent whether dead or dying plants with rotten or broken rootstocks were first attacked by root maggots or were invaded by rot fungi without prior maggot attack. To determine whether maggots were present, scoop out the soil around the roots with a trowel to a depth of 10-15 cm and spread this soil on the ground; if root maggots were present, puparia should be present.

Estimate the population of puparia overwintering in fields after the crop has been cut (but before cultivation) by turning over the soil within a one square metre area with a trowel following a random sampling plan.

Economic threshold

Economic thresholds are not established.

Management Strategy

Cultural practices

The effect of different cultural practices on the level of root maggot infestation has not been investigated. Crop rotation is unlikely to have an effect because the flies disperse from fields in which they emerge and locate new crops by odor.

CLOVER CUTWORM

Discestra trifolii

Insect Life Cycle

Host plants

Clover cutworm larvae are above-ground feeders on the foliage of most vegetables, flax, canola, sunflowers, alfalfa, clover, peas, beans and sugar beets. Many weed species complement the clover cutworm's diet such as Russian thistle, lamb's quarters and redroot pigweed.

Overwintering

The species overwinters as pupae in the soil.

Spring appearance

Overwintering cutworm pupae emerge as moths from the

end of May through June with the peak in the first half of June in southern Alberta. Emergence may be delayed by cool spring weather. Dates of emergence may be one or two weeks later in the north.

Number of generations

There are two generations per year. Moths of the second generation appear in late July or August.

Damage Assessment

Economic importance

Clover cutworm is a recurrent problem in canola grown in the Peace River region and is a sporadic pest of truck crops and sugar beets in the south. Clover cutworm infestations

on canola were prevalent in the Peace River area in 1982. The insect is generally not present in economically injurious numbers.

Damage description

There are two generations of clover cutworm in Alberta. Eggs are laid on the underside of leaves in late spring and during summer. Newly hatched caterpillars feed on the underside of lower leaves, gradually moving up the plant as they mature. Damage from the first generation occurs from approximately late June through July and from the second generation from mid August through September.

Second generation larvae of clover cutworm may be present at the same time as bertha armyworm larvae. While bertha armyworms tend to be dispersed throughout fields, clover cutworms have a more clumped distribution, so damage is more concentrated.

Larvae eat the foliage and pods from canola plants and, when present in high numbers, strip plants completely. Larval infestations and adult flights tend to be localized with apparently suitable nearby habitat remaining undisturbed. Shortage of food, a result of severe infestation, will cause larvae to march en masse into nearby fields.

Sampling and monitoring methods

Clover cutworm is one of several cutworm species monitored with pheromone traps. Monitoring of this species is limited to the Peace River region, where it is a recurrent pest of canola.

Sample numbers of larvae by beating plants in an area 50 cm x 50 cm. Record the number of larvae on the ground. Repeat this procedure several times in different locations. Then calculate an average number of larvae per square metre for the field.

Economic threshold

The economic threshold for this insect is probably similar to that for bertha armyworm (See the bertha armyworm section to determine thresholds from sampling data). Second generation larvae frequently cause damage at the same time as bertha armyworms. In years when both species are present, clover cutworms may be mistaken for bertha armyworms.

Management Strategy

Cultural practices

Normal rotation of canola with cereal crops will minimize infestations because adult dispersal to new areas is slow. Fall plowing will expose pupae to predators and freezing temperatures.

Biological control

Parasites, predators, disease and inclement weather have checked past infestations of clover cutworm on canola grown in the Peace River region. High mortality of the climbing cutworms is common from natural causes after a short period of high population density.

DARK-SIDED CUTWORM

Euxoa messoria

Insect Life Cycle

Host plants

The dark-sided cutworm can cause serious damage to seedlings and transplants of most vegetables and field crops. Plants attacked include peas, beans, potato, tomato, cucumber, melon, sweet pepper, asparagus, alfalfa, corn, barley, strawberries and spruce seedlings.

Overwintering

Eggs overwinter in cultivated fields on the soil beneath plants and debris.

Spring appearance

Larvae hatch from overwintered eggs during the first period of extended warm weather in spring. During the day, larvae remain in the soil at the base of plants on which they feed at night. Mature larvae pupate in the soil. Moths are active from late July to early September.

Number of generations

There is one generation per year.

Damage Assessment

Damage description

Larvae feed on emerging plants at or below the soil surface. They may completely consume above-ground portions of small plants, especially the succulent ones that have recently been transplanted. These larvae may even climb trees to injure buds. Crop damage is most severe from May 15 to the end of June.

Sampling and monitoring methods

Dark-sided cutworm is one of several cutworm species monitored throughout the province with pheromone traps. This provincial monitoring program began in 1985.

Economic threshold

An economic threshold has not been established for dark-sided cutworms.

Management Strategy

Cultural practices

Weed control and the destruction or plowing under of crop trash soon after harvest, preferably before August, will help to reduce egg production.

DIAMONDBACK MOTH

Plutella xylostella

Insect Life Cycle

Host plants

The diamondback moth is a sporadic pest of cabbage, cauliflower, Brussels sprouts, broccoli, turnip, mustard, rape and canola. The moth also feeds on several species of weeds in the mustard family. It does not attack cereals.

Overwintering and spring appearance

The diamondback moth does not overwinter in Alberta but is carried on winds from the United States each spring. The number of spring migrants and their establishment is weather dependent, so advance forecasts of early infestations are not possible. By late summer most canola fields are infested to some extent. The size of the first immigration, the number of additional immigrations, and the size of each are factors that determine the potential abundance of moths each year. The availability of suitable food for first generation larvae may also be important.

Number of generations

There are three generations of moths per year, the first migrating from the United States in early May or June. Later in the summer, generations overlap so that all stages may be on host plants at the same time.

Natural enemies

Predators - Include mites, spiders, lacewings, predatory plant bugs and three species of birds.

Parasites - No egg parasites have been found. At least 10 species of parasitic insects attack the larvae and pupae; the most important of these kills an average of 50 to 60 per cent of the pest population.

Pathogens - Disease seems to be a minor mortality factor.

Damage Assessment

Damage description

Damage to canola by young larvae is characterized by small holes and surface stripping on the undersides of leaves as well as small white mines in the leaves. Older larvae feed on flowers, young pods, and surface tissue of stems and mature pods, usually from mid July to early August.

Yield losses are caused by feeding on the surface of immature pods. Seeds under these damaged areas do not fill properly; the pods are more susceptible to early shattering. In severe cases, damage appears from a distance as an abnormal white color. After an infestation is controlled in a pod crop, a new infestation is not likely to become established because of the rapid advancement of the crop toward maturity.

In general, the second generation larvae cause yield loss only during the peak flowering to early pod formation in canola (often about the last week in July). The third generation is likely to affect only unusually late maturing crops.

Although they usually attack only the leaves of host plants, older larvae often feed on the florets of cauliflower and broccoli and bore into the heads of cabbage and the sprouts of Brussels sprouts. Pupae on the heads of wheat at harvest develop from larvae that fed on mustard family weeds or volunteer canola in the wheat field. This pest does not attack cereals.

Sampling methods

Beat plants within 50 cm x 50 cm areas and count larvae on the ground. Multiply by four to get the number of larvae per square metre.

Economic threshold

An average of 200-300 larvae per square metre may warrant control when they occur at the same time as canola pod development. Damage to pods is most severe when canola leaves have dropped. Normally larvae feed on leaves and do not move to pods unless leaves are not available.

Management Strategy

Effects of weather

A major cause of larval deaths is rainfall. Larvae are washed from leaves and drown in water in leaf axils or in pools on the ground. This affects young larvae the most. Older larvae are affected less because they are not easily washed off and can climb back on the plants more readily if dislodged. Larvae are more susceptible to harm by rain in cold than in mild weather. These effects of summer rain may explain why infestations appear to be more frequent in the Prairies than elsewhere in Canada.

Another factor that controls diamondback moth abundance is the weather during the egg-laying period. Cool cloudy weather reduces moth flight activity. The longer that inclement weather persists, the more females die before egg deposition is completed.

Cultural practices

The factors responsible for the potential abundance of this

pest are the size of the spring immigration and the availability of suitable food for first generation larvae. If the moths arrive before preferred hosts emerge, alternate host plants will include volunteers and other weeds on summer fallow. Tillage reduces the availability of suitable host plants and thus the successful establishment of first generation larvae.

EUROPEAN CORN BORER

Ostrinia nubilalis

Insect Life Cycle

European corn borer was accidentally introduced into North America. The first Canadian record is from Ontario in 1920. The species became so important in the 1920s that the Government of Ontario passed the Corn Borer Act which enforced the application of certain control measures. The corn borer was found in Alberta in 1956.

Host plants

Sweet corn is the preferred host, but grain corn is also damaged. Over 200 other plants are hosts including potato, tomato, tobacco, oats, soybean, white beans, sugar beet, broom millet, hops, and various weeds and ornamental plants. In Canada, this species attacks these plants only under abnormal conditions, for example when corn is absent. However, since corn was not native to Europe, this pest must have developed on alternate hosts and adapted to corn over time.

Overwintering

European corn borers overwinter as fully grown larvae in corn stalks, cobs and plant debris on the soil surface.

Spring appearance

In late spring the larva chews an exit hole from its overwintering cell in plant debris and then returns to spin a cocoon in which to pupate. Beginning in mid-June, moths emerge in early morning, they fly between half-an-hour and four-and-one-half hours after sundown, with a second minor flight near dawn. Wind does not prevent flight; the moths fly into a slight wind. They are attracted to light. They fly to hosts such as tall grass, to mate and begin egg development. Peak egg laying and flight occur around the middle of July. Females lay up to 500 eggs during this time.

Number of generations

Only one generation per year occurs in the Prairies, although a second flight of adults, peaking in late August, sometimes occurs in the Medicine Hat area.

Natural enemies

Predators - European corn borer is attacked by many natur-

al enemies throughout its life. Lady beetles and other insects and predacious mites feed on the eggs and young larvae. Beetles enter the borer tunnels to feed on plant sap and injure borers and crowd them out of the tunnels. Downy woodpecker, ring-necked pheasant and other birds dig overwintering borers out of their chambers in corn-stalks and plant debris.

Parasites - Three of the 17 species of parasitic wasps and flies introduced to Canada between 1923 and 1940 for corn borer control became established.

Native species of *Trichogramma*, a group of tiny wasps, attack the eggs of European corn borer.

Pathogens - A protozoan, *Nosema pyrausta*, weakens the borer so that infected larvae suffer heavier winter kill, and infected moths lay fewer eggs than healthy moths. This protozoan plays a moderate to significant role in reducing borer populations.

Two other protozoa, *Varimorpha* species, infect the borer under laboratory conditions. One is extremely virulent and looks promising as a microbial control agent.

Beauveria bassiana, a widespread fungus, will kill more than 50 per cent of the overwintering borer population in a given year. Outbreaks of *B. bassiana* occur most readily during ample rainfall, with temperatures about 30°C.

The potential of the bacterium, *Bacillus thuringiensis*, as a microbial control agent of corn borer has been studied. This bacterium produces spores and crystals. In laboratory tests, both spores and crystals retarded growth of the borer. A combination of spores and crystals killed larvae. A recently registered granular formulation of *Bacillus thuringiensis* is effective on corn borer.

Nuclear polyhedrosis viruses isolated from alfalfa looper and a mint looper will infect the borer. Viruses hold promise as control agents.

Damage Assessment

Damage description

All above ground portions of the corn plant can be attacked. Young larvae bore into growing whorls where

they feed on developing leaves and give them an etched or shot-hole appearance. Young larvae that bore in the leaf midrib will cause leaf breakage. Feeding in developing tassel stalks weakens them so they are easily broken off by the wind. Older larvae bore into stalks and ear shanks and disrupt the normal movement of nutrients and water, which reduces yield. Stem breakage and ear drop are common damage symptoms. Another symptom is boring dust or frass that resembles small balls of sawdust in the leaf axils and on kernels within the ear. Damage to sweet corn ears makes them unmarketable. Tunnels permit secondary infection and damage by stalk and ear rot fungi.

Sampling and monitoring methods

Moth activity can be used to determine duration and intensity of moth flight and when to begin field scouting. Chart the number of European corn borer moths caught per night in a light trap to monitor nightly flights. During the day, moths may be flushed from grassy field margins, weedy fence rows and other areas of dense vegetation, where moths congregate, mate and feed. These sites of dense vegetation are necessary stopover points for female moths before egg deposition in the cornfield. Locating these action sites and observing moth activity can be very helpful. The number of female moths in the grass around field edges, along waterways and between the rows of weedy fields correlates with the number of egg masses deposited on corn plants. Three females per square metre equals 0.5 egg masses per corn plant. With good weather, this level of infestation could mean economic losses.

Walking through the action site will cause the moths to flush. The flush method correlates well with the drop-net method for monitoring adult populations. An average of 61 moths (males and females) within a 1 m x 10 m area is equivalent to an average of three females per square metre. A minimum of five flush samples should be taken in the grass for every 20 acres of cornfield. This adult flushing technique is a useful way to determine whether scouting for egg masses should be started.

The best scouting methods produce estimates of the total field population. You must take good, representative samples. Take a minimum of five random samples of 20 consecutive plants each. The first sample should be taken beyond the edge of the field to eliminate the "edge" effect. Remaining samples should be taken randomly across the entire field. Be careful to consider all representative topographical and other features that may influence plant height, plant maturity and plant density. If more than one variety is planted in the same field, consider each variety as a separate field and sample separately. If the field is larger than 40 acres, divide the field into 40 acre blocks and consider each block a field. Record all observations.

Examine plants for shot holes in the leaves and balls of sawdust-like material in the leaf axils. Record the number of plants damaged. Dissect two infested plants per sample

of 20 and look for live borers. Check for live larvae; borer mortality in the first three to five days after hatch is normally very high.

Economic threshold

The economic injury level (EIL) is the pest population density at which the value of actual or potential damage equals the cost to prevent the damage. The economic threshold (ET) is the population density at which control measures should be initiated to prevent the pest density from surpassing the EIL.

To apply these concepts to the European corn borer, the theory of a treatment window must be introduced. Only larvae that have not bored into the plant can be killed. Consequently, there is a specific time period, or "window", during which pesticides must be applied if they are to be effective. Because egg deposition in a given field may last two to four weeks, insecticides must typically be applied before all eggs have been deposited; otherwise, larvae from eggs deposited early in the egg laying period will enter the plant. The decision to treat must be based on an estimate of the potential European corn borer population density in the field. The potential population density may be estimated as follows:

1. Scout the field weekly for borer egg masses. Include your count of the hatched egg masses. Or, as previously described, flush the weedy areas around the field for adults.
2. Begin counts of borer egg masses per plant with the first sign of borer eggs in the field. Researchers believe that it is unlikely that eggs can be detected before 5 per cent of the eggs are in the field. This assumption becomes an integral part of calculating the potential population density.
3. Calculate the potential population density (PPD) per plant as:

$$PPD = \frac{(SV)(23)(EM)}{PO} \quad \text{where,}$$

SV = the average proportion of individuals that survive to damage corn. Based on studies from Iowa and Kansas, a value of 0.2 is recommended.

EM = the number of egg masses per plant. This is multiplied by the average number of eggs per mass (23).

PO = the proportion of the total egg complement deposited before detection in the field = 0.05.

4. Sample the field and calculate PPD again in eight days. Assume at this time that 50 per cent of the egg complement has been laid based on an assumption of a three week egg laying period. Thus, PO = 0.5 for the second calculation of PPD.

Although ET is usually less than EIL, in this case ET = EIL because we are making the control decision before all of the borer population is present in the field (so the insect is destroyed before it reaches the damaging stage). The ET (EIL) may be estimated as follows:

1. Determine the cost of control (dollars per acre). This includes the cost of insecticide and the cost of application by ground or air.
2. Estimate the market value of the crop (dollars per bushel of corn) at the intended time of sale and the crop yield (bushels per acre) at harvest.
3. The ET is then calculated by:

$$ET = \frac{CC/MV}{(DL/100)EY} \quad \text{where,}$$

CC = control costs (\$/ac),

MV = market value (\$/bu),

DL = percentage damage loss (per borer per plant) at the time of infestation (percentage loss column from the table at the end of this section), and

EY = estimated yield (bu/ac).

At this point the treatment decision can be made by comparing the potential population density (PPD) to the economic threshold (ET). If PPD is greater than or equal to ET, then treatment is warranted. For example: Assume that on the second sampling date (eight days after initial borer detection and during pollen shed), you counted 15 egg masses per 100 plants sampled.

$$\begin{aligned} PPD &= \frac{(SV)(23)(EM)}{PO} \\ &= \frac{(0.2)(23)(0.15)}{0.5} \\ &= 1.38 \text{ larvae/plant} \end{aligned}$$

After talking with the aerial applicator, you determine that control costs will be \$16 per acre for a single insecticide application. You estimated that the crop will yield 140 bushels per acre and that you will receive \$3.40 per bushel at sale.

$$\begin{aligned} ET &= \frac{CC \text{ MV}}{(DL/100)EY} \\ &= \frac{\$16.00 \quad \$3.40}{(4.4/100) \quad 140 \text{ bu}} \\ &= 0.76 \text{ larvae/plant} \end{aligned}$$

In this example, PPD (1.38 larvae per plant) is greater than ET (0.76 larvae per plant) and treatment is economically justified.

Corn loss caused by European corn borer and calculated economic injury level (EIL) for various corn growth stages.

Plant stage	Bu/ac loss (/ECB/plant)	% loss (/ECB/plant)	Calculated EIL*	
			1 Appl.	2 Appl.
Early whorl	7.7	5	1.4	2.1
Late whorl	6.2	4	1.8	3.6
Pretassel	9.2	7	1.2	2.4
Pollen shedding	6.2	4	1.8	3.6
Kernels initiated	4.2	3	2.6	5.3

Source: Iowa State University publication No. 327, 1989.

*Assume: Cost of control (CC)=\$16.00/ac per application. % Loss column = proportion of yield lost per ECB (DL). Market value (MV)=\$2.00/bu Expected yield (EY)=150 bu/ac. Proportion of ECB population killed = 0.67.

This procedure was used in 1981 during a pilot European corn borer management program, and the proper treatment decision (based on a single insecticide application) was reached in seven of eight Kansas fields. Work in Alberta to verify results from the U.S.A. is still in progress. Potential users of this procedure must remember that virtually any factor that affects one of the variables in the equations could cause you to reach an economically unjustified treatment decision. Assumptions that concern the length of the egg-laying period (which influences PO), the proportion of larvae that survive (SV), and the damage loss relationships (DL) are the weakest portions of the procedure.

Management Strategy

Cultural practices

Corn borer adults are strong fliers and can be dispersed by wind. Transportation of infested plant material such as corn silage or corn cobs can spread the larvae.

Tillage - Cultural practices can greatly reduce corn borer infestations. Ideally, all crop residues should be cut for silage or shredded for fodder immediately after harvest. The remaining stubble should be disced and plowed under 10-15 cm. Ridging may be necessary to cut down the risk of soil erosion. If proper cultural control cannot be implemented in the fall, corn residue and stubble should be plowed down in early spring (by May 1). Avoid deep cultivation of infested fields that were plowed down to prevent bringing up buried corn stubble.

Variety selection - Plant corn hybrids that mature early so that fields can be plowed as early as possible in the fall. European corn borer was eradicated in Alberta 30 years ago by methods similar to those recommended above. Tolerant or resistant corn varieties, are not yet available in Alberta.

Population monitoring - Chemical controls may be effective if applied within a few days after eggs hatch and larvae start to feed. Once larvae enter the stalk, no controls are available. Use light traps or pheromone traps to determine the time of moth flight. Scout fields to determine the size of egg populations and the time of hatching. This information will help the operator choose the best time to apply insecticides. More than one application may be necessary depending on the length of the adult flight and subsequent hatching period.

Trap strips - Recent research suggests that populations of

corn borer larvae can be kept below economic levels by a combination of grass and weed control with control of adult moths. Cornfields should be kept relatively free of grass and dense weeds. Waterways and field edges should be mowed. Corn borer moths may then be confined to selected patches of grass and killed with non-persistent insecticides. These trap strips or patches of grass are necessary where most grassy areas have been mowed. They prevent resident and immigrant moths from seeking cover in untreated grass near adjacent fields. Moths that find alternative sites may return to lay eggs in the fields with borders and waterways that have been mowed.

FLEA BEETLES

Phyllotreta spp., *Psylliodes punctulata*

Insect Life Cycle

Host plants

Adult flea beetles become active in April and early May, mate and feed on leaves of available weeds of the mustard family such as flaxweed, stinkweed, wild mustard, lamb's quarters, volunteer canola and pepper grass.

Overwintering and spring appearance

Flea beetles overwinter as adults under leaf litter and other ground debris in grassy headlands, fence rows and wooded areas. The three economically important species of flea beetles have slight differences in timing of life cycle stages; for instance, the hop flea beetle emerges earlier from hibernation and the crucifer flea beetle emerges later than the striped flea beetle. The crucifer flea beetle, *Phyllotreta cruciferae* and the striped flea beetle, *P. striolata*, are the most persistent pests and were introduced to North America from Europe; the hop flea beetle, *Psylliodes punctulata*, occasionally attains pest status and is most common in irrigated areas.

Number of generations

Only one generation of flea beetles is produced each year.

Natural Enemies

Parasites - Some wasp parasites of flea beetles affect only a small proportion of the population.

Damage Assessment

Damage description

Most damage to canola is done by adult beetles just before or after seedlings have emerged from the soil. Flea beetles hop into canola crops from the borders when temperatures are below 18°C, and fly when the temperature is higher.

They chew small holes in the cotyledons and leaves. Damaged

plants typically have a "shot hole" appearance when the tissues around the feeding sites in the cotyledons and leaves die. Losses caused by flea beetles are due to reduced plant survival, smaller and weaker plants, and delayed plant development and maturity. All contribute to reduced yield. This is especially true if the weather is hot and dry.

Canola seedlings can withstand significant leaf area removal in the cotyledon stage under good growing conditions without significant reduction in yield. With heavy and continuous attacks, seedlings may wilt and die, particularly when feeding is combined with poor plant growth during hot, dry weather. Heavy infestations may destroy the entire crop and reseedling may be necessary.

Once the crop reaches the three- or four-leaf stage, the plants are generally established and can outgrow the feeding damage. At this time, the number of adult flea beetles often begins to decline.

The new generation of adults emerges in late July through early August. They skeletonize leaves and chew the epidermis from stems and pods but do not cause economic damage if the seeds are sufficiently developed. Late maturing canola is, however, at greater risk. Cool, wet weather reduces feeding activity and favors plant growth. Hot, dry conditions promote crop damage by beetle adults.

Sampling methods

Use the amount of defoliation as a gauge for insecticide application. The key point to remember is that the amount of defoliation is frequently overestimated. Collect plants at random throughout the field and estimate the foliage damage. Canola seedlings can withstand 50 per cent leaf loss. Flea beetles generally invade fields from the edges. If temperatures are above 18°C, however, and beetles are flying, you should select plants at various intervals as you walk into the field. At each location estimate leaf loss. Check all field and slough margins where the insect overwinters. This sampling procedure determines the extent and distribution of damage.

Daily inspection of newly emerged plants is necessary to identify flea beetle damage as it develops. A foliar-applied insecticide may be needed if flea beetles are numerous on the plants or on the soil, beetle feeding damage is in excess of 50 per cent of the cotyledon or leaf area, and the weather is warm and dry. If damage is only along the field margins and beetles are still congregated there, then controls measures should be applied to damaged areas only. Seed dressings and granular insecticides can be applied with seed to control flea beetles. This may have less environmental impact than application of foliar sprays.

Management Strategy

Cultural practices

Very few cultural or preventive controls are available. Allowing cruciferous weeds to grow in summer fallow fields may reduce damage if flea beetle populations are high.

Control cruciferous weeds and volunteer canola in cereal fields to starve out early spring populations. In addition, in the spring leave a trap strip of volunteer canola near overwintering sites and cultivate the remainder of the field. Spray this trap strip before beetles move into seedlings.

GRASSHOPPERS — CLEAR-WINGED

Camnula pellucida

Insect Life Cycle

Host plants

The clear-winged grasshopper is mainly a grass feeder. Economic damage is primarily to cereals, especially wheat and barley. Clear-winged and migratory grasshoppers have together destroyed areas of range grass and hay almost entirely.

The nutritional qualities of the chief food plant can affect longevity and egg production of grasshoppers. Kentucky blue grass is one of the best foods for high survival and egg production. Western wheatgrass is one of the worst foods for grasshoppers and could be a factor that limits distribution of this grasshopper on the Prairies. It may be the only green grass available to attract females at egg laying time.

Spring appearance

If the previous fall was warm, eggs of the clear-winged grasshopper will be the last of the pest grasshopper species to hatch. They hatch in late May to early June. The embryos of this species undergo a maximum of 50 per cent of their total development before winter. The other pest species can complete more of their development in the fall and consequently need less time in the spring to complete pre-hatch development.

Overwintering

Clear-winged grasshopper eggs are laid in the fall and hatch the following spring. Each female lays an average of eight egg pods (about 175 eggs) usually in unbroken sod. The short vegetation of dry, mowed roadsides and sparse, over-grazed pastures is especially favored for egg deposition. Males are conspicuous at egg laying sites; their undersides become bright yellow during the mating and egg laying period. They stake out a territory and wait for females to come to oviposit.

Number of generations

As with all of Alberta's grasshopper pests, clear-winged grasshoppers have one generation per year.

Natural enemies

Next to weather, natural enemies are the grasshopper's most important population control factor. In some localized areas natural enemies may cause even more mortality than the weather.

Some enemies attack when grasshoppers are still in the soil awaiting spring. Others attack nymph and adult stages.

Predators - Among the most important egg predators are bee flies, blister beetles, ground beetles and crickets. Common field crickets eat the eggs and may destroy up to 50 per cent of the eggs in some areas. Bee flies and blister beetles deposit their eggs in the soil near grasshopper eggs. When the larvae of these egg predators hatch, they locate the egg pods and feed upon the eggs. If bee flies and blister beetles are abundant, they may destroy up to 80 per cent of eggs in a localized area.

Spiders, some wasps and many birds feed on grasshoppers and consume large numbers of nymphs and adults. Their effect on the total grasshopper population is not known.

Parasites - A few other insects, such as the tiny wasps of the genus *Scelio*, parasitize eggs just after they have been laid. The young parasitic larvae complete their development within the eggs in time to emerge as adults and parasitize the eggs of the next generation of grasshoppers. They may destroy from 5 to 50 per cent of the grasshopper eggs.

Parasites of nymphs and adults include flesh flies, tachinid flies and tangled-veined flies. Fly larvae burrow into the grasshopper when they contact it on the ground. Other fly larvae are deposited on or into the grasshopper's body by the female fly. The maggot then feeds inside the grasshopper and eventually kills its host as the maggot leaves the body. This group of insects may parasitize up to 60 per cent of the nymphs and adults.

Threadworms attack grasshoppers if the young worms encounter a grasshopper or if grasshoppers eat threadworm eggs. Threadworms overwinter in soil and lay their eggs on the soil or on vegetation.

Pathogens - The fungus, *Entomophthora grylli*, can effectively control grasshoppers under warm, humid conditions.

This fungus may occasionally reach epidemic proportions. The disease leaves the corpses of its victims clinging to the stems of plants.

The microsporidian parasite, *Nosema locustae*, is an effective enemy of grasshoppers. A grasshopper becomes infected if it eats contaminated vegetation or a diseased grasshopper. A grasshopper population infected with this organism may be reduced by as much as 60 per cent in one year. It also reduces the number of eggs laid and restricts the movement of individuals and thus affects grasshopper populations. Perhaps this organism's greatest potential as a biological control agent, however, is for reducing food consumption.

Since most of the natural enemies of grasshoppers are already widespread, it is unlikely that they could be used to prevent grasshopper outbreaks over extensive areas. Nevertheless, natural enemies do control localized grasshopper infestations and hasten the decline of grasshopper outbreaks.

Poultry - During the depression, some farmers successfully used turkeys to control grasshoppers. In years when grasshoppers were plentiful, the turkeys were simply released into fields. This resulted in a secondary benefit: the turkeys required little supplemental food since grasshoppers provided a plentiful high quality protein diet.

Other birds - Gulls, hawks, crows, meadowlarks, crowned larks, lark buntings, desert horned larks, shrikes, curlews, killdeer, partridges and cranes are all predators of grasshoppers. Many birds scratch up the egg cases, and have been credited with clearing from 5 to 150 acres of grasshopper pods. Birds, especially gulls and meadowlarks, are credited with stopping some infestations in the early part of the century. This is more likely to happen if a habitat provides food and refuge for the birds. Farm habitat can be made more attractive to birds and so encourage predation of insect pests.

Vertebrates other than birds - Most animals are opportunists; they will eat what is nourishing and available to them. Mice, rats, shrews, gophers and badgers all eat grasshoppers and their egg pods. Coyotes, skunks, lizards, snakes, toads, bobcats and kit foxes eat nymphs and adults.

Damage Assessment

Economic importance

Clear-winged grasshopper has been on average, the most economically important species of grasshopper in Canada, although over the years its importance relative to other species has changed gradually. The first record from the Prairie Provinces was from Saskatchewan in 1800. Clear-winged grasshoppers did not become abundant, however, until about 1900 when road-building, drainage and cultivation in southern Manitoba created favorable breeding sites and greatly increased the abundance of suitable food plants. In recent years there has been a marked decrease in

the intensities of outbreaks in Manitoba. This may be related to changes in agricultural practices that have reduced populations of certain grasses.

Damage description

Damage to cereal crops is generally concentrated near field margins and is caused when hatchling grasshoppers move out of egg beds into field edges; damage to grasslands tends to be more evenly distributed. Damage to cereals includes leaf notching and stripping but is most costly when stems are severed just below the heads of maturing or mature crops. When grasshopper numbers are extremely high and natural plant hosts in short supply, grasshoppers will consume or attempt to consume any plants or plant products that they come upon during their migrations in search of food.

Sampling and monitoring methods

Walk through the infested area and estimate the number of grasshoppers per square metre as they jump in front of you. A sampling 'T' as depicted below will likely improve your estimate. The 'T' consists of a metre-long measuring stick, carried by a handle so that a square metre can be visualized at crop height. Walk and carry the 'T' just above the crop.

Late summer and fall surveys of grasshopper adults have been carried out by agriculture fieldmen in Alberta since 1932. Grasshopper forecast maps are produced yearly from data collected in about 1,700 townships.

Spring surveys of grasshoppers and grasshopper eggs are also conducted in years when high grasshopper numbers are expected. In this way, improved estimates are obtained for time of hatch, population density and the effects of predators and parasites.

Economic thresholds for grasshoppers

	Number of grasshoppers/m ²	
	Field	Roadside
Control not usually required	0 - 6	0 - 12
Control may be required	7 - 12	13 - 24
Control required	13+	25+

Management Strategy

Effects of weather

Population size is primarily determined by weather. Outbreaks are usually preceded by two to three years with hot, dry summers and open falls. Dry weather increases the probability of egg survival, hastens spring hatch, and promotes nymphal development and adult feeding. Open falls allow grasshoppers more time to feed and lay eggs. Cool, wet weather increases egg mortality by promoting fungal diseases, retards nymphal development, reduces the numbers of eggs laid by delaying sexual maturity and reduces the activity of grasshoppers at all stages.

Cultural practices

Tillage - Cultivation is probably the most effective cultural practice available to farmers for the reduction of grasshopper populations. Tillage controls grasshoppers primarily by eliminating the green plants on which grasshoppers feed.

However, tillage is of little value for the sole purpose of physically destroying grasshopper eggs or exposing them so that they dry out or are eaten by birds and other insects. Excessive tillage may also increase the risk of soil erosion.

Tillage to eliminate weeds from summer fallow fields during late summer and early fall will discourage female grasshoppers from depositing their eggs in these fields. Grasshoppers seldom lay eggs in clean summer fallow even when it has a heavy cover of trash. Similarly, thorough cultivation of fields immediately after harvest will help discourage grasshoppers from laying all their eggs within the field.

Complete spring tillage before grasshoppers hatch to eliminate all green growth on stubble fields that are to be in summer fallow. If no food is available when grasshoppers hatch, they will starve to death because they are unable to move long distances to find food. Early tillage will also give good weed control and conserve moisture at no extra cost.

Trap Strips - If grasshoppers are present when tillage operations begin, elimination of all green plant material in a field will probably not achieve adequate control. Once grasshoppers have fed and developed to the second stage of growth (second instar), they usually are mobile enough to move to adjacent crops when their food supply becomes exhausted. Use trap strips in these fields to collect grasshoppers into a relatively small area where quick and economical control will be possible with a minimum of insecticide.

To make strips, cultivate a black guard strip 10 m wide around

the outside of a field. Leave an uncultivated green strip at least 10 m wide before resuming cultivation. Repeat the process as often as necessary to produce additional trap strips. All green vegetation must be eliminated between the trap strips if they are to be effective. The black guard strip will ensure that grasshoppers promptly move into the trap strips to feed.

The effectiveness of trap strips can be improved considerably by seeding them to wheat, barley or oats several weeks before tillage begins. Trap strips should have adequate vegetation to feed even the largest of grasshopper populations for three to five days.

Migration of young grasshoppers from the cultivated guard strips to the trap strips may take several days. Once the migration is complete, the trap strips and a 10 m strip of adjacent crop should be treated with insecticide. Apply the highest recommended rate of insecticide to ensure adequate control.

Before cultivating the trap strips, allow three days to assess the effectiveness of the insecticide. If adequate control is not achieved after three days, treat the trap strip again. When grasshoppers have been eliminated from the trap strip, it should be possible to complete tillage without fear of displacing large numbers of grasshoppers into adjacent crops.

Summer fallow that is not properly managed can be a major source of grasshoppers. Many cases of growers applying insecticides six or seven times to a field border are a direct consequence of improper grasshopper control on summer fallow.

Early seeding - Seed crops as early as possible. Older plants can withstand more grasshopper damage than younger plants that are not well established. Although early seeding may not totally prevent crop damage, damage will be reduced and more time will be available to apply insecticides. Also, crops that are seeded earlier will mature earlier and migrating grasshoppers are not as likely to be attracted to them.

Crop rotation - Whenever possible, avoid seeding cereals on stubble fields heavily infested with grasshoppers. Seed cereals only on stubble fields where soil moisture is adequate and where one or more applications of an insecticide over the entire field is economical.

Canola seeded with an in-furrow application of a granular insecticide may be a suitable alternative to cereals where grasshopper infestations are light.

Roadside vegetation management - Certain of our common roadside weeds, such as stinkweed, alfalfa and dandelion, are nutritious food plants for nymphs and adults. Such plants promote high survival and egg laying. Western wheatgrass on the other hand, is one of the poorest food plants.

GRASSHOPPER — MIGRATORY

Melanoplus sanguinipes

Insect Life Cycle

Host plants

The migratory grasshopper is one of the most destructive pests in western Canada. Outbreaks can lead to costly losses for grain growers. This species attacks both field and garden crops, especially cereals, tomato, celery, onion and carrot.

Overwintering

Females lay pods of about 25 eggs in stubble and wheat fields, between clumps of grass or in other patches of dry soil during August and September. The eggs of this species and others in the genus *Melanoplus* can complete up to 85 per cent of their embryonic development before winter.

Spring appearance

Eggs hatch between early May and mid July, although the date depends upon temperature and moisture conditions in

both spring and the preceding fall. Watch for signs of hatching in stubble fields and along roadsides and pastures where adults were seen in August and September.

Number of generations

As with all of Alberta's pest grasshopper species, migratory grasshoppers have one generation per year.

Natural enemies

See clear-winged grasshopper

Damage Assessment

Economic importance

The migratory grasshopper is normally the most numerous pest grasshopper species in Western Canada and is often injurious to cereals.

GRASSHOPPERS — PACKARD'S

Melanoplus packardii

Insect Life Cycle

Host plants

Packard's grasshopper prefers herbs to grasses and hence causes little damage to range land, but will damage field and garden crops and legume pastures. It feeds on leaves, stems and flowers of many plants. Cereals and alfalfa are heavily attacked.

Overwintering

Females lay one to several egg pods in grain fields or along roadsides, mostly in August and September. Each pod contains about 20 eggs. The egg stage overwinters.

Spring appearance

Eggs hatch between early May and mid July, depending upon temperature and moisture conditions. Nymphs, which are green or fawn colored, molt through five nymphal instars before becoming adult in three to seven weeks. In cooler seasons, development is slowed and nymphs persist into the fall.

Number of generations

There is one generation per year.

Natural enemies

See clear-winged grasshopper.

Damage Assessment

Economic importance

Packard's grasshopper occurs in the four western provinces. It is the second most important species of grasshopper in Alberta, and the third most important in Saskatchewan where it has comprised 12 per cent of the total grasshopper population. It tends to be associated with the migratory grasshopper, *M. sanguinipes*, and tends to occur especially in stubble fields and in light soil areas. Packard's grasshopper has caused considerable damage to fall rye and winter wheat.

Management Strategy

See clear-winged grasshopper.

GRASSHOPPERS — TWO-STRIPED

Melanoplus bivittatus

Insect Life Cycle

Host plants

Two-striped grasshoppers feed on grasses and broad-leaved plants. The broad-leaved plants are necessary for maximum growth. They prefer the lush growth around edges of streams, marshes and cultivated fields. Hosts include weeds and most crops, especially alfalfa and vegetables, and occasionally trees and shrubs. They were first noted in large numbers in 1932 after broad-leaved weeds became common on the Prairies.

Overwintering

This species overwinters in the egg stage. Drift ridges of soil in abandoned fields that suffered severe wind erosion are favored egg laying sites. Other areas include heavier textured soils along roadsides, closely cropped pastures, fence rows, ditch banks, prairie sod and field margins, but not cropped fields.

Air temperature must be above 20°C and soil moisture between 10 and 20 per cent for egg deposition to occur. Forty to 100 eggs are laid per pod; only two or three pods are laid by each female during August and September.

Spring appearance

First instar nymphs appear in late May to early June.

Number of generations

There is one generation per year.

Natural enemies

The two-striped grasshopper has a greater number of natural enemies of the egg stage than have the clear-winged or migratory grasshoppers. The nymphs and adults are attacked by at least twelve species of insect parasites, two mermithid nematode species, three microbial pathogens and by various birds, small mammals and parasitic mites. Insect parasites are most abundant two or three years after an outbreak. There are various records of heavy mortality from fungus disease to which the two-striped grasshopper seems particularly susceptible. Red mites have infested up to 100 per cent of a population; however, about eight per cent is a more normal figure. Their effect on these grasshoppers is unknown.

Damage Assessment

See clear-winged grasshopper.

Management Strategy

See clear-winged grasshopper.

GREENBUG

Schizaphis graminum

Insect Life Cycle

Host plants

The greenbug feeds on cereals and forage grasses. Late-sown oats, barley, fall rye and wheat are usually susceptible when this aphid is abundant, although in one year the greatest injury was to early-seeded fields of winter cereals. Timothy grown for forage is most susceptible because of succulent growth that appears after harvest.

Overwintering and spring appearance

The species is normally unable to survive the winter in Canada. Infestations are begun mainly by flying aphids that are carried into Canada on southerly winds. The species passes the winter on fall planted wheat and volunteer grains in Oklahoma and Texas. It migrates north in the spring, and passes through several generations during migration. The numbers that eventually reach Canada are presumably influenced by whether migrating individuals find suitable food plants, conditions suitable to successful colonization, and southerly winds when populations are flying. In 1986, infestations in southern Alberta did not arrive until early July.

Number of generations

The greenbug produces many generations each season. The number of generations that can be produced in Alberta depends on the time of initial infestation, crop condition, and temperature.

Natural enemies

Predators - Lady beetles (lady bugs), lacewings, big-eyed bugs.

Parasites - Parasitic wasps.

Pathogens - Various fungal pathogens.

Damage Assessment

Economic importance

The greenbug, an introduced species, has been on the Prairies since 1907. Greenbugs are not normally a problem because they do not overwinter in Alberta. Heavy migration and outbreaks do occur and large areas were infested in the 1930s and in 1986. This species of aphid injects a

toxin into plants while feeding. The toxin causes brown spots at sites where aphids feed and causes the plant to turn yellow. Plants are set back from their normal maturity date. The aphid can carry barley yellow dwarf virus and maize dwarf mosaic virus.

Damage description

The condition of host plants may influence infestations; in one instance damage to late seeded barley and oats was highest in low lying land that had been flooded earlier. In another instance, serious outbreaks were attributed to the coincidence of aphid flight with a time when late crops were at a succulent stage of development. Late-seeded crops are more susceptible because they are less able to withstand attack, have more attractive succulent growth, and are less likely to produce a crop should plants recover.

Damage is caused primarily by the toxin that is injected into the plant. Aphid colonies are on the lower parts of the plant; necrosis (browning) of lower leaves occurred throughout infested fields during the 1986 outbreak. From a distance, however, fields took on a yellow appearance that was evident, on close inspection, in the top growth. In many barley fields, the unnatural yellow color was likely

attributed to severe scald and net blotch, which were prevalent in 1986.

Economic threshold

From 5 to 25 aphids per stem warrants chemical control action, that is, the economic threshold is dependent on the stage of crop growth, the health of the crop and growing conditions. Abundant predators and parasites should enable greater populations to be tolerated.

Management Strategy

Effects of weather

The species has been abundant in hot dry weather. Cool weather may prevent population increases. Rain can wash migrating aphids out of the air.

Biological control

Predators, especially lady beetles, have prevented population increases and controlled outbreaks.

LYGUS BUGS

Lygus spp.

Insect Life Cycle

Host plants

Lygus bugs feed on a wide variety of crop plants but alfalfa and canola are preferred. Weed hosts include flxweed, kochia, lamb's quarters, mustard, Russian knapweed and Russian thistle.

Overwintering and spring appearance

Lygus bugs overwinter as adults under debris, litter or plant cover along fence lines, ditch banks, hedgerows and in wooded areas. In the spring, adults become active, feed on early growing plants and mate. Lygus bugs migrate to crops when they become suitable for feeding and egg laying. This may be as early as mid May in the southern prairies and as late as mid June in the Peace River areas.

Number of generations

Lygus bugs have two or three generations per year.

Natural enemies

Predators - Damsel bugs, ladybird beetles, green lacewings, pirate bugs, big-eyed bugs.

Parasites - Lygus bugs are attacked by a nematode and by an insect parasite that also attacks four other species of plant bugs found in forage crops.

Damage Assessment

Economic importance

Lygus bugs are general feeders and are found on many herbaceous plants. They are most damaging to alfalfa grown for seed but also actively feed on canola. The tarnished plant bug, *Lygus lineolaris*, feeds on a wide variety of forage crops, vegetables, fruits and flowers and is the most economically important lygus bug on the prairies. Two other Lygus species, *L. borealis* and *L. elisus*, are also pests of canola and alfalfa seed production.

Damage description

In northern parts of the Prairie Provinces and British Columbia these bugs often cause bud blasting and prevent alfalfa from blossoming. When alfalfa is attacked while in bud, the buds turn white and fail to develop, the flowers fall without forming pods, the pods fall off before they are mature, or the seeds are discolored or shrunk. In one instance 10 to 25 per cent of blossoms were destroyed and in another, lygus-damaged seed averaged 25 per cent of yield. One heavy infestation in

alfalfa was caused by bugs that migrated from nearby snowberry. On alfalfa, eggs are laid in upper parts of the plants. Populations tend to build up quickly when alfalfa is grown under irrigation and when the weather is damp. However, lygus bug populations tend to remain low when the weather is hot and dry. Wet weather may prevent seed from setting and in turn may obscure any damage that the bugs cause. Cool weather reduces feeding activity.

Lygus bugs puncture tissues and suck plant juices. Plants also react to the toxic saliva the insects inject when they feed. Lygus bug infestations can cause alfalfa to have short stem internodes, excessive branching and small, distorted leaves.

Lygus adults also feed on the base of canola buds and flowers and cause blast damage quite similar to that in alfalfa. Buds that are attacked appear shrunken and bleached. In late July and early August, older nymphs and adults puncture pods and suck out the contents of immature seeds. Damaged seed appears dark brown and shrivelled. A droplet of fluid may be on the exterior of the pod at the puncture site.

Sampling methods

Sample the top 20-25 cm of the crop with a sweep net.

Economic threshold

In alfalfa grown for seed the economic threshold is two or three adults or five nymphs per sweep during bud and bloom and four adults per sweep after bloom.

Management Strategy

Biological control

Controls in alfalfa grown for hay are not necessary because natural predators and parasites, along with mowing and harvesting, reduce lygus bug populations.

Cultural practices

Control tarnished plant bug, *Lygus lineolaris*, in ornamental plants by removing weeds and keeping lawns or grassy areas mowed to eliminate breeding sites.

PALE WESTERN CUTWORM

Agrotis orthogonia

Insect Life Cycle

Host plants

Pale western cutworm is important as a pest of wheat. It can also damage rye, oats, barley, mustard, flax, sugar beets and legumes. Pale western cutworm feeds thistles and various other weeds.

Overwintering

Eggs are laid just below the surface in loose friable soil, in cracks in hard-packed soil, and in stubble fields. Females lay 150 to 400 eggs during August and September before frost kills the adults. Egg deposition occurs in late afternoon and early evening.

Spring appearance

Eggs hatch between the end of March and the beginning of May. There is sometimes abnormal hatching in the fall if the weather is cool. The newly hatched larvae can withstand starvation for several weeks. Freezing temperatures are not a serious hazard to survival and hatching of the egg. Larvae feed on growing leaves below the soil surface.

Number of generations

There is one generation per year.

Natural enemies

Frequent rainfalls saturate the soil and force larvae to the surface where they are exposed to attack by predators, including birds, beetles and ambush bugs. On the surface they feed on the upper parts of plants where tachinid fly parasites lay eggs. Excessive moisture apparently has no significant effect in reducing cutworm numbers in the absence of parasites and predators. In dry weather, parasitism is low and the effects of predatory birds and insects are negligible.

Damage Assessment

Damage description

The first sign of injury is the appearance of small holes in rows across the leaves. These holes are caused by larvae that feed on the curled leaves when they are underground. As the leaves emerge the holes become apparent. Cutworms at this stage are very small and difficult to find. As larvae increase in size, they move along the row and cut off leaves and often entire plants. This behavior is similar to that of redbacked cutworms. Injury caused by older cutworms may be distinguished from drought by pulling up the plant. Cutworm injury is the likely cause when roots do not come out with the plant stem. If the entire plant can be easily pulled up, drought is the probable cause. Older larvae chew and weaken stems just below soil level and make the crop susceptible to wind damage. Damage ranges from complete destruction of individual fields to partial destruction over thousands of acres. Outbreaks have occurred on the Prairies with no apparent pattern since 1911.

Sampling and monitoring methods

Since 1978, pale western cutworm moths have been monitored with pheromone traps in southern Alberta. In 1985, a province-wide pheromone monitoring system was established for this and other cutworm species.

Sample for numbers of larvae as for other subterranean cutworm species. Mark an area of soil 50 cm x 50 cm. During the day, larvae are within the top 5-7 cm of soil. Count the larvae within the quarter square metre. Repeat the process in different areas of the field. Calculate an average number of larvae per square metre for your field.

Economic threshold

Infestation levels of 10 cutworms per square metre in winter wheat or three or four per square metre in spring cereals, generally warrant an insecticide application. If there are more, or if obvious thinning of the stand has occurred, immediate control is necessary. Infestations may be patchy within fields, and evident especially on high areas and hill tops. Examine the edges of bare patches to determine the cause of an uneven plant distribution.

Management Strategy

Effects of weather

Many infestations have been halted, reduced or prevented by wet weather. Frequent rains also reduce damage by promoting plant growth. Conversely, damage can be severe when the spring is dry. If there are fewer than 10 wet days in May and June, cutworm populations tend to increase. Drought can delay egg laying and kill larvae by desiccation, which may explain why there can be less damage in dry than moist soil. Usually a spring with 12 or more wet days will reduce the cutworm population to a point where two or three dry springs are needed to develop a population that can cause damage. A wet day is any day the soil is too wet to use a disc-harrow.

Cultural practices

Cultural practices can influence cutworm populations. Disturbing the soil during August and early September tends to promote infestations in the following year because the soil surface is more suitable for egg production. A soil disturbance that affects egg production can include harvest activity, cultivation or grazing. A crust on the soil of summer fallow fields left undisturbed during August and September inhibits infestations in the following year.

Tillage for weed control - In May, a delay of five days or more between cultivation and seeding can stop an infestation. The larvae will die if they feed after they hatch and then are deprived of food for several days, or if they cannot feed at all for 10 to 14 days. Warm, sunny weather will shorten this period.

Timing of this first tillage operation is important. Cultivate the field when the vegetation is 2-5 cm above the ground

surface. If the land is cultivated too early, before the cutworms start to feed, they will simply remain inactive and cannot be starved out.

Do not use stinkweed as an indicator plant for deciding when to cultivate to destroy weed growth. Stinkweed is usually the first plant to appear in the spring. Cutworms do not feed on this plant, however, and will not become active until later.

Control by starvation is effective if done properly but has a serious disadvantage because seeding of wheat may be delayed for too long. Barley, flax or a greenfeed crop may have to be sown in place of wheat. Even if wheat can be sown the shorter growing season may reduce yield. In view of the disadvantages this control method should only be used on fields disturbed during a heavy egg laying period the previous year.

Crop rotation - Fields should not be disturbed between August 1 and mid September to discourage cutworm egg production. The following rotation may be useful:

- 1st year: Seed summer fallow to fall rye before August 1; the rye may be grazed after September 15.
- 2nd year: Harvest rye before August 15.
- 3rd year: Seed oats or barley as a nurse crop to sweetclover and cut for hay or greenfeed about July 15; the crop can be pastured after September 15.
- 4th year: Cut sweetclover for hay in late July or for seed after September 15.
- 5th year: Plant spring wheat and follow it with a year of summer fallow.

Biological control

Parasites and predators are unlikely to be effective in dry weather.

PEA APHID

Acyrtosiphon pisum

Insect Life Cycle

Host plants

Field peas and alfalfa in the irrigated areas of southern Alberta may be severely damaged by the pea aphid, *Acyrtosiphon pisum*. This insect, which also feeds on sweetclover, trefoil, vetch, sweet peas, broad beans and several varieties of clover, is found in Alberta wherever peas and forage legumes are grown.

Overwintering

Pea aphids overwinter as eggs on leaves and stems of various perennial legumes.

Spring appearance

A small, light green, wingless female hatches from each egg when plants resume growth in spring. These female aphids, called "stem mothers", reproduce without mating. They feed on the growing plants and give birth to other female young. Some aphids of the second and third generations become winged and migrate to peas and other acceptable host plants. Here they feed and produce wingless females that give rise to other generations of both winged and wingless females.

Number of generations

Generation time and numbers of offspring produced are factors greatly influenced in aphids by temperature and food quality. Accordingly, aphids develop from birth to maturity in five to 50 days. All pea aphids are female throughout spring and summer; a summer female can produce from 50 to 150 young during its life.

Natural enemies

Predators - Syrphid fly larvae, and adults and larvae of ladybugs, lacewings, damsel bugs, pirate bugs, lygus bugs and predacious plant bugs.

Parasites - Pea aphids are parasitized by tiny wasps, which lay one egg inside each aphid. The wasp larvae eventually kill their hosts.

Damage Assessment

Damage description

This aphid generally infests the growing tips of plants. Both adults and young pierce plant tissues and suck juice from leaves, petioles, stems and flower buds.

Most healthy plants can withstand moderate infestations without showing damage. However, large populations cause alfalfa plants to become stunted and wilted. Upper leaves become light green, and lower ones turn yellow and

die. Yield and quality of hay may be greatly reduced. From a distance, the affected area of an alfalfa field appears brownish, and close examination reveals shed aphid skins on the ground beneath the plants. Where growth of alfalfa is retarded, weeds may take over and crowd out the alfalfa. Large numbers of aphids are a nuisance during haying, cubing and dehydration.

This aphid transmits viruses such as alfalfa mosaic, alsike clover mosaic, bean yellow mosaic, pea enation mosaic, pea mosaic, pea streak, and red clover vein mosaic. However, these diseases have been of minor importance in Canada.

Sampling and monitoring methods

The simplest way to determine aphid densities in alfalfa is with a sweep net. A 38 cm diameter fine net bag with a 1 m handle is commonly used. Move through the crop and sweep the net in a 180° arc through the tops of the plants five times; that is, make five sweeps. Count the aphids collected or estimate their number if they are too numerous. Calculate the average number per sweep. Repeat the process in four different spots in the field. In field peas, count the aphids on at least 20, 20-cm stem tips taken from four different spots in the field.

Economic threshold

The economic threshold varies with yield expectation, commodity price and cost of control. In alfalfa, 150-200 pea aphids per sweep justifies control. Assess the density of pea aphids in field peas when the crop begins to flower. If the economic threshold of 9-12 aphids per sweep or 1 - 4 per 20-cm stem tip is exceeded, protect the crop against yield loss with a single application of insecticide when 50 - 75 per cent of the plants have begun to flower.

Management Strategy

Effects of weather

Weather favorable for rapid growth of alfalfa greatly reduces the possibility of aphid damage. Aphid infestations may be reduced by very hot weather and retarded by cold weather. Heavy rains may dislodge and kill aphids.

Cultural practices

Resistant and susceptible varieties - Several varieties of peas, including Pride and Onward, are not severely damaged by aphids.

Most pea fields in Manitoba had aphid densities that exceeded the economic threshold from 1980 to 1983. Aphids reached higher densities on the cultivar Trapper than on Century. Thus, control is more likely to be required in fields of Trapper.

Fababeans were severely damaged by pea aphids in greenhouse tests. In the field, however, this crop is planted early and seems to be past the susceptible stage when aphids migrate from perennial crops.

Harvesting - Cut alfalfa hay in the early bloom stage, remove the hay from the field quickly and irrigate immediately to reduce aphid damage to new plant growth. This allows the crop to become well established before the aphid population again becomes large.

Biological control

Predators and parasites help to keep the pea aphid under control. Usually they become abundant only when the aphid is abundant. The predators are mainly adults and larvae of damsel bugs, pirate bugs, ladybird beetles and lacewings, and larvae of syrphid flies. The parasites are the larvae of tiny wasps, which live in the aphids and eventually kill them. When aphids are unusually abundant, spiders and birds also eat them.

A fungal disease may sometimes eliminate infestations of aphids in warm moist weather.

PRAIRIE GRAIN WIREWORM

Ctenicera aeripennis destructor

Insect Life Cycle

Host plants

The prairie grain wireworm is the most destructive wireworm pest of grain in Western Canada. It prefers annual and perennial grasses. It also attacks potatoes, sugar beets, corn, lettuce, sunflower, canola and onions.

Overwintering

Wireworms (the larval stage) live for several years in the soil and are quite resistant to adverse conditions. Those larvae that survive their first winter can go for at least two years without any food other than humus. The wireworm stage lasts anywhere from four to 11 years. They hibernate in the soil from 5 to 25 cm below ground level. Older larvae commonly feed to a depth of 15 cm in the topsoil. When fully grown, usually in July, the larvae pupate about 5 to 10 cm below the soil surface. Pupation lasts for less than a month; however, adults do not emerge until the following spring.

Spring appearance

Wireworm adults, called click beetles, emerge in April and early May from the soil in which they overwintered. They become active when the air temperature is above 10°C, mate and then seek egg laying sites. From late May through June individual females deposit 200 to 400 eggs in loose soil, or under lumps of soil. Depending on the moisture, temperature and firmness of the soil, eggs are laid anywhere from just below the soil surface to 15 cm deep. After three to seven weeks, the wireworms hatch and begin to feed on live roots or seeds of cereals or grasses. If no food is found within one to four weeks of hatching, the larvae die.

Number of generations

The generation time (4 to 11 years) varies with the quality and availability of food. Wireworms in all growth stages are likely to infest a field.

Natural enemies

Parasites - Parasitic nematodes attack larvae.

Pathogens - Larval mortality caused by bacterial diseases is especially high in soils with a high moisture content.

Damage Assessment

Economic importance

In Alberta, damage to wheat crops ranges from one to 50 per cent annually. Damage to other non-cereal crops varies from farm to farm. Over 80 species of wireworms occur in Alberta, but only the prairie grain wireworm is of major economic importance.

Damage description

The larvae feed on germinating seeds or young seedlings and shred the stems but seldom cut them off. The central leaves die but outer leaves often remain green for some time. Damaged plants soon wilt and die, resulting in thin stands. Poor seed and dry conditions can also cause thin stands; consequently, many wireworm infestations are passed off as due to poor seed or poor germination.

Wireworms do the most damage in early spring when they are near the soil surface. During summer months, larvae move deeper into the soil where it is cool and moist.

Wireworms do not ingest solid plant material, but chew tissues, regurgitate fluids containing enzymes, and then imbibe the juices and plant products made soluble by the enzymes.

Potato seed pieces are seldom damaged to a point where poor stands result. However, new tubers can be damaged severely. Tunnels made by the wireworm allow disease organisms to enter, and the damaged tubers are less marketable.

Damage is generally higher in silty, medium textured, well-drained soils and in soils cultivated for at least 12 years. Damage is less likely in heavy or very light soils. Crops grown in newly broken sod can suffer great losses for one to two years, then the damage decreases rapidly

only to gradually increase in succeeding years if no wireworm control measures are applied.

Sampling and monitoring

Whole potatoes buried in marked locations in a field in the spring or from early to mid August will indicate whether wireworms are present. Bury the potatoes 10 to 15 cm deep then dig them up after a couple of weeks, and examine them for wireworm tunnels. Monitor your fields each year.

To sample for larvae, sieve the soil through a screen. Mark out areas 50 cm x 50 cm and sieve the soil to a depth of 15 cm. Repeat in different areas of the field to determine an average number of larvae per square metre.

Economic threshold

None have been established. Treat seed for two consecutive years after breaking sod to reduce the problem to a non-economical level.

Management Strategy

Effects of weather

Larval activity is governed by temperature and moisture conditions. Cool wet weather forces wireworms closer to the surface; dry hot weather forces them deeper into the soil. Cool weather restricts adult activity and lengthens the egg laying period. Eggs laid near the soil surface or in compact soil are subject to high mortality when moisture levels and temperature fluctuate rapidly. Mortality is from 92 to 98 per cent in eggs and young wireworms. Most wireworm mortality occurs during the first two weeks of larval life.

Cultural practices

Crop rotation - Crop rotation and other cultural practices usually prevent wireworms from becoming a major problem in sugar beet fields. Because sugar beets are normally grown in a four-year rotation in Alberta, crops less susceptible to wireworm attack can be grown on infested fields so that populations will not build up. Root and row crops such as potatoes, corn, onions or beans should not be grown in a rotation where wireworms have been a problem. Wireworms can also be present when sugar beets are grown on land previously uncultivated or planted to grass or pasture. Deep plowing in the fall and frequent cultivation in early summer are suggested when wireworms are known to be present in these fallow fields.

Shallow cultivation - The long life and underground habit of wireworms make them hard to control. The most vulnerable period for the wireworm is from the egg to early larval stage. Only two to eight per cent of eggs and young wireworms survive. Newly hatched wireworms must feed within four weeks. Thus, cultivate fallow land in early spring to starve hatchlings. Shallow cultivation in early spring can

expose eggs and injure larvae. Thorough cultivation of summer fallow during the latter half of July can destroy pupae as well as larvae. Use a rod weeder and disturb only the upper soil layer.

Summer fallow - Summer fallow for wireworm control is not recommended, because it has almost no effect on mature larvae, which can survive for two years on soil humus alone. In fact, wireworm damage is more severe after fallow. If early spring cultivation is used to starve and injure young larvae and eggs, plant a resistant crop.

If summer fallow must be part of the rotation, starve newly hatched wireworms by destroying all green growth during June and July. Work summer fallow as shallow as possible for weed control. Seed shallow, pack the seedbed to induce quick germination, and avoid very early or very late seeding.

Shallow cultivation or seeding combined with soil packing - Pack behind the seed drill to reduce damage to grain in wireworm infested land. Wireworms are very poor travellers. Some remain in the larval stage for nine or 10 years during which time they travel only a few yards. Firming the soil further impedes wireworms. Use a press drill for best results. If a press drill is not available, use a packer hitched behind the seeder in such a way that all wheels of the packer "follow" the drills of the seeder. Thus, the seed row is packed firmly, making wireworm movement so difficult that most of the worms will seek their food in the looser soil between the seed rows. If the packers do not follow the seed rows they will tend to leave them loose while firming the intervening strips. This may encourage the worms to follow the seed rows and cause heavy damage.

Farmers should restrict tillage operations to the upper 5 to 8 cm of the soil to maintain a compact soil layer beneath the tilled layer.

Adult click beetles are also affected by a compact sub-layer because they are forced to lay their eggs close to the surface, where the eggs can easily dry out or be discovered by predators.

Seeding practices - Avoid very early or very late seeding. Use methods that speed germination and early growth of the crop to help reduce the impact of wireworm damage. Cultivate before spring seeding to give the crop a competitive advantage with weeds and to prepare a good seedbed. On land that was in summer fallow the year before, a rod weeder will produce a very compact seedbed. On stubble, use a one-way disc; then seed at the proper time. If the soil is moist, seed 10 to 14 days from when drilling was first possible so that the soil is warm and seeds will grow quickly. If the soil is dry, delay seeding until it rains. As much as 90 to 95 per cent of a crop has been destroyed when seeded into a dry soil compared with 5 to 10 per cent loss when seeded into moist soil. Moisture also helps young seedlings recover from wireworm damage.

Shallow seeding - Seed preferably at a depth of 2 to 5 cm. This speeds the early growth of plants (as long as moisture is present). Use a drill press or standard drill with press attachment. If not available, use a standard double disc

drill. Avoid the use of single-disc drills, and hoe-drills; but if you must use them, use press attachments or follow with a packer.

Increase the seeding rate in fields infested with wireworms, especially for wheat. Use as much as an extra bushel per acre, or for a patchy infestation, drill twice. Use healthy seed. A light topping of rotted manure or an application of phosphate fertilizers will help reduce wireworm damage. The phosphorous in the manure probably encourages root development and early maturity. Manure can be applied late in the fallow year or early the next spring, and should be incorporated into the soil.

Do not plant susceptible crops on the same land in two successive years. A crop rotation with resistant varieties and legumes is useful.

Buckwheat and flax are not usually damaged by wireworms. If recommended seeding practices are followed, oats and barley can be planted except when infestations are severe. Fall rye and winter wheat are more resistant owing to early vigorous growth in spring. However, a wet autumn preceded by a dry summer and fall has resulted in damage to rye. Plant legumes with a light nurse crop or in a mixture

with a grass. Seedlings of sweetclover and alfalfa can be seriously damaged by wireworms. The seedlings usually escape damage in a mixture. Mature plants are not damaged by wireworms.

Take special precautions after breaking sod. If a crop on new land is destroyed, reseed immediately with a resistant crop. This is preferable to leaving the land fallow, since a recurrence of the problem would then be likely.

Biological control

Parasites - A few nematode parasites control wireworms that pupate below ground. At present these nematodes are not available for commercial use.

Pathogens - Wireworms are susceptible to bacterial and fungal diseases, and mortality is higher in moist soils.

Predators - Click beetles and their larvae are prey to both birds and small rodents. The adults are preyed upon when they lay eggs, the larvae are eaten in spring when they are near the surface or when exposed by cultivation. Birds pull them from the soil, and moles and shrews dig for them.

REDBACKED CUTWORM

Euxoa ochrogaster

Insect Life Cycle

Host plants

Redbacked cutworm is primarily a pest of cereals, sugar beet, canola, mustard, and flax in the Prairie Provinces. It also feeds on most vegetables, sunflower, sweetclover, alsike, alfalfa, various tree seedlings and garden flowers.

Overwintering

Redbacked cutworm moths usually lay their eggs just below the soil surface in weedy summer fallow and in weedy patches in crops. The eggs overwinter.

Spring appearance

Eggs usually hatch in April as soil temperatures increase. Larvae begin feeding immediately on any nearby plants and feed for six to eight weeks with most of the damage occurring in June. Larvae generally remain inactive during the day, but at night either come to the surface or move underground in search of food plants.

Number of generations

There is one generation per year.

Natural enemies

Parasites - Natural enemies suppress outbreaks and presumably contribute to the relatively low populations that usually occur in the two or three years following outbreaks. Parasitism must be sufficiently low to permit an infestation of redbacked cutworms to develop. No parasites were found in one severe outbreak and parasite numbers were low in the year preceding an outbreak year.

Pathogens - Heavy mortality of the larvae from disease occurs in outbreaks. In British Columbia, this pest is attacked by 18 species of parasitic insects, five species of fungi and three other kinds of microbial pathogens.

Damage Assessment

Economic importance

Redbacked cutworm frequently causes serious damage on the Prairies and produces infestations of two to four years duration followed by a minimum of two years of relative scarcity.

Damage description

Damage by young larvae is characterized by small holes and notches in foliage. Older larvae eat into stems and usually sever them at or just below the soil surface.

Infestations in cereal crops are characterized by areas of bare soil that gradually enlarge until anywhere from one to two acres to complete fields are affected. Damage is often patchy and occurs on knolls and in light soil areas. These bare areas of exposed soil are often confused with areas of poor germination or moisture stress. The presence of cutworms is characterized by severed, dead, dried plants.

Sampling and monitoring methods

Redbacked cutworm moths have been monitored with pheromone traps since 1978 in southern Alberta. In 1985, a province-wide pheromone monitoring system was established for this and other cutworm species.

Sample for larvae as for other subterranean cutworm species. Mark an area of soil 50 cm x 50 cm. During the day, larvae are within the top 5-7 cm of soil. Count the larvae within each 0.25 m². Repeat the process in different areas of the field. Calculate an average number of larvae per square metre for the field.

Economic threshold

Economic thresholds are not firmly established but five to six cutworms per square metre may justify control. Well established fall-seeded or spring-seeded crops with good moisture conditions can tolerate higher numbers.

Infestations may be patchy within fields. Examine the edges of bare patches to determine the cause of uneven plant distribution.

Management Strategy

Effects of weather

Augusts that are hot and dry provide the best conditions for moth feeding on flowers. Egg production and egg laying depend on the nutrition obtained from flowers. The same weather conditions promote the loose, dry soil surfaces necessary for egg deposition. Cold weather may be detrimental to larvae and pupae. Wet, warm weather promotes plant growth and fungal diseases in the larvae. Warm, dry weather can increase the severity of damage from cutworm attack.

Cultural practices

Tillage Practices - Crusted soils on summer fallow help prevent egg deposition from late July until late September. Destroy weed growth that develops in August, because redbacked cutworm moths usually lay their eggs in weedy summer fallow. They also lay in weedy patches in cereal crops and in fields of canola, peas, alfalfa and sweetclover. To starve young cutworm larvae before spring seeding, allow volunteer growth to reach 3 to 5 cm, cultivate and then seed 10 to 14 days later. Locate cutworms by digging 2 to 3 cm below the soil surface at the edge of the damaged area.

Biological control

Because parasite numbers tend to increase after an increase in abundance of the host, very few parasites are found during the first year of an outbreak. However, after two years, parasites are numerous enough to reduce the outbreak and keep cutworm numbers low for at least two years.

RED TURNIP BEETLE

Entomoscelis americana

Insect Life Cycle

Host plants

The red turnip beetle is an occasional pest of canola and mustard in Western Canada. It is native to Canada and is most common in the aspen parklands and Peace River district. The larvae and adults feed on seedling plants in May and June, and the adults feed on mature plants in August and September.

Food plants of larvae include canola, yellow mustard oriental mustard, brown mustard, dog mustard shepherd's purse, wild mustard, flaxweed, tall hedge mustard and black mustard. Other common cruciferous weeds that might serve as food plants for the larvae include ball mustard, tumble mustard, wormseed mustard, gray tansy mustard, green tansy mustard, marsh yellow cress, pepper grass, small-flowered prairie-rocket, false flax, hoary cress and hare's-ear mustard. Neither larvae nor adults feed on stinkweed.

Overwintering

Red turnip beetles overwinter in the egg stage. The eggs hatch in April and early May, shortly after the snow has melted and usually before canola is planted.

Spring appearance

Upon hatching, the black, rough-skinned larvae feed on canola, mustard and weeds of the mustard family. Larvae normally complete development by the end of May and enter the soil to pupate.

The adults normally emerge during the first three weeks of June and feed for two to three weeks, usually in the same fields in which the larvae fed. At the end of June, the adults enter the soil to spend July in a resting state (aestivation). They reappear in August, disperse to new canola and mustard fields, mate and lay eggs until late October.

Number of generations

There is one generation per year.

Natural enemies

Predators - Carabid beetles.

Pathogens - A microsporidian causes disease.

Damage Assessment

Economic importance

The only damage of economic significance is caused by the adults in June.

Damage description

In May and June, infestations of both larvae and adults occur in canola and mustard stubble fields and in other fields with heavy stands of cruciferous weeds. If these food plants are all consumed, the larvae and adults may invade nearby fields of seedling canola and mustard. They crawl or walk to new fields and usually are concentrated in a moving front only a few metres wide. Adults do not fly in June.

Larvae and adults feed on the cotyledons, true leaves, petioles and stems of seedlings. Depending on seedling size and red turnip beetle abundance, damage will vary from the loss of small portions of cotyledons and true leaves to complete defoliation and death of plants. Small seedlings are more readily damaged than large seedlings. If beetles are numerous, they gradually move into a field, destroying most of the plants as they go. Larvae generally are not a problem because they complete development before the new crops have germinated. Adults may cause sufficient damage in June to warrant control measures.

In August, adults invade canola and mustard fields soon after re-emerging and feed on the flowers, pods and stems of plants until harvest. However, the numbers of adults normally are not large enough to significantly reduce seed yield. Control measures to protect yields are not required in August and September.

Sampling methods

If large numbers of adults invade newly seeded canola and mustard fields in June, it may be necessary to use insecticides. Examine fields carefully to determine the extent of invasion and whether the beetles are causing economic damage. Because they walk into the fields at the margins and are concentrated in a moving front, it usually is necessary to spray only a small part of each field. If the invasion occurs late in June, the adults likely will not cause economic damage because they will soon aestivate.

If the size of the invasion is small or if the beetles enter only a small area (or both), chemical control may not be necessary.

Economic threshold

Economic thresholds have not been established. However, in assessing damage and potential for economic damage, two factors should be considered: date of invasion and stage of plant development. Because adults feed for only two or three weeks in June, they will damage rapeseed and canola for less than three weeks. If adults enter fields soon after emergence in early June, they will probably destroy many more plants than if they enter shortly before aestivation in late June, because they have a longer time in which to feed and the plants are smaller. Beetles cause less damage in fields with relatively large plants than in fields with small seedlings.

Management Strategy

Cultural practices

Infestations of red turnip beetle usually originate in canola and mustard stubble fields and other fields with heavy stands of cruciferous weeds that were not cultivated in the previous fall and spring. These infestations can be reduced considerably or prevented completely with good cultural practices. Cultivation of fields after harvest buries the eggs and thereby kills 75 - 100 per cent of the next generation because newly hatched larvae cannot reach the soil surface in the spring. Destruction of larval food plants by cultivation or a herbicide application in April and May will also eliminate most larvae through mechanical injury; many will starve because they can travel only short distances for food. Mechanical injury and desiccation after cultivation in May and June will kill many pupae.

Double seeding along field edges next to fields infested the previous year should reduce the number of insecticide applications that are required. Since beetles move en masse, one or two passes with a sprayer along the field margin, over and in front of invading insects, will provide control.

Crop rotation to a non-cruciferous crop is another way to prevent losses caused by this insect. But take care! Adults have caused damage in canola fields situated next to fields where canola was underseeded to fescue the previous year and therefore not cultivated.

SWEETCLOVER WEEVIL

Sitona cylindricollis

Insect Life Cycle

Host plants

Sweetclover is the preferred host, but this weevil will feed on alfalfa or cicer milk vetch if no sweetclover is available.

Overwintering

The adults overwinter in a sexually immature condition in the stubble and trash of sweet clover fields and in ditches and wastelands where sweetclover is common.

Spring appearance

Spring populations may number 40 to 170 per square metre. The weevils fly readily with the wind when temperature and light intensity are high and humidity is low. They feed at night on the upper leaves and hide when disturbed by light. They hide by day at the bases of plants. Each overwintered female lays several hundred eggs from late May to early August by dropping them indiscriminately on the soil. Larval populations may be 50 to 800 times the size of the spring adult population.

Number of generations

There is one generation per year.

Natural enemies

Pathogens - A fungus disease that commonly attacks the adults has caused up to 80 per cent mortality.

Predators - The weevils are eaten by toads and grubs.

Damage Assessment

Economic importance

This is the major insect pest of sweetclover. It has caused serious damage to sweetclover throughout Alberta. Damage is mainly to young plants. There are records of almost complete loss of crops in individual fields. Because seedlings are killed quickly, the harm caused by this pest is often overlooked or improperly blamed on poor germination or poor tillage methods. Severe losses can be caused by the combination of damage by this pest and either root rot (which the larvae are suspected of carrying) or dry weather (which retards seed germination and seedling growth). There are wide fluctuations in the relative abundance of this pest in different years. Populations can be high; in one infestation there were more than 2500 larvae and 1000 adults per square metre; in another, almost complete destruction of some fields was caused by an average of 1000 adults per square metre.

Damage description

Adults chew crescent-shaped, jagged notches in leaves and can completely defoliate plants. They may even eat the outer tissue of stems and green seeds in pods. Damage is most severe in dry years. Seedling crops can be severely thinned or completely destroyed if adults move into a field. Second year stands can be thinned or stunted from the feeding of overwintered adults. Sweetclover weevils drop from plants when disturbed and are very difficult to find. The larvae are root feeders. Plant growth does not seem to be affected, however, despite the presence of abundant larvae.

First-year sweetclover crops planted near or in succession to older crops are especially liable to severe damage, particularly when the second-year crop is cut for hay. Sweetclover is attacked in grain stubble but apparently is not harmed in corn crops or corn stubble. Alfalfa and alsike clover are sometimes damaged after nearby fields of sweetclover have been harvested. Adults are found on red clover but apparently do not feed on it.

Sampling methods

Inspect clover seedlings for weevil damage in spring as the seedlings emerge. Weevils may not be seen, but the typical crescent-shaped feeding notches on the leaves are very noticeable. In midsummer and throughout August, inspect first-year clover stands for damage along crop margins. Invading weevils move into these stands only as far as necessary to satisfy their food requirements, so an insecticide application to affected field margins is usually all that is required.

Visually estimate the number of weevils per plant. This must be done carefully because weevils fall from plants easily and cannot be seen when on the ground. The damage is more obvious than the weevil.

Economic threshold

In a seedling crop under slow growth conditions — one weevil for every five seedlings at the cotyledon stage (first leaves prior to true leaves). Under normal growth conditions — one weevil for every three seedlings at the cotyledon stage. In newly emerged second-year crops — 9 - 12 weevils per plant.

Management Strategy

Effects of weather

Weather is an important regulator of the size of insect populations. Wet weather seems to be harmful to this pest. Heavy rainfall tends to reduce the effects of damage and helps plants outgrow the damage. Dew and high humidity inhibit the movement of weevils up the plant at night and probably help spread the fungus disease that commonly

attacks the adults. The effects of dry weather are mixed. Cold dry weather in May and June may promote a population increase; but hot dry weather may to favor larval survival. The dry weather augments the effects of attack by the weevils. Hot dry weather reduces pest numbers by hardening the soil, which prevents larvae from reaching the roots, and probably kills eggs and newly emerged adults. In one survey a larval population of over 1,700 per square metre was reduced to only 300 per square metre after a hot dry spell. In hot dry weather there is high adult mortality and complete mortality of larvae from eggs laid after July in hot dry soil. Over a four year period in Manitoba, mortality ranged from 95.5 to 99.9 per cent, much of which occurred between the fourth instar and adult emergence.

Cultural practices

Several management practices reduce losses from sweetclover weevil. Arrange crop rotations so that clover fields are as far apart as possible. Weevils that disperse in spring and late summer will be less likely to find the first-year crop. Sow clover early (before grain crops) into a firm, moist seedbed and at the recommended shallow depth. This promotes even germination, a fast start, and hardy vigorous

seedlings. Cultivate clover fields, silage and hay, as soon as the crop is removed. Cultivation kills the larvae while they are still on the roots.

Blade cultivation following removal of a hay crop has been recommended as a control measure but apparently has no effect on weevil populations. Plowing to a depth of 15 cm in October has prevented over 90 per cent of the weevils from emerging from hibernation. Plowing, discing and cultivating 7 to 12 cm of second-year fields immediately after the hay was harvested has killed 96 per cent or more of the weevils. Tillage of field margins in the fall and planting new fields as far as possible from existing ones are believed to lessen the possibility of severe infestations. Control volunteer sweetclover around fields the year before planting the field to sweetclover to reduce the possibility of field invasion and damage by weevils.

Biological control

Next to weather, diseases are most important in population control. The weevils are eaten by toads and grubs. A biological control attempt in Manitoba in 1959 that used imported parasites was not successful.

WHEAT STEM SAWFLY

Cephus cinctus

Insect Life Cycle

Host plants

Wheat stem sawfly is native to North America and lives in grasses, mostly the wheatgrasses, *Agropyron*. Cultivated hosts include wheat, rye, triticale and some varieties of barley. Within the wheats, spring wheat is most heavily attacked in Alberta; winter wheat appears to have become a potential host in Alberta only within the last few years. In Montana, winter wheat has been severely infested and is perhaps the major host there. Winter wheat is occasionally attacked in southern Alberta in counties bordering Montana. The old varieties of durum wheat were resistant to wheat stem sawfly but some new varieties are susceptible. Oats and broad-leaved crops are immune. Female wasps will lay eggs in barley but the larvae don't live long enough to cause yield losses. Plant age is important to egg-laying females. Plants that have not reached the jointing (stem elongation) stage are not acceptable to females. Similarly, plants in the boot stage are immune to sawfly attack.

Overwintering

The sawfly larva feeds within the stem and burrows down to or below ground level by the time the wheat heads begin to ripen. It then turns around, head upwards, and cuts through the stem about 2 cm above the ground, seals the end above itself, spins a cocoon in the stem and passes the winter as a larva in diapause (hibernation).

Spring appearance

Overwintering larvae pupate within their cocoons in May; adults begin to emerge in early June from stubble fields and native grasses. As is common for many insects, males start to emerge first followed within a few days by females. A study in northern Montana showed peak male emergence occurred about June 15th and peak female emergence about June 25th. They are rather inactive insects that drift from plant to plant and spend most of their time resting on grass stems.

Number of generations

Wheat stem sawfly has one generation per year.

Natural enemies

Parasites - There are nine known parasites of wheat stem sawfly; only one species, however, provides significant control. *Bracon cephi*, a native braconid wasp, is one of the few insect parasites that can move from grass to crops with the sawfly. When weather conditions delay crop maturation and sawfly larval development, *B. cephi* can produce another generation, thus extending its control of the wheat stem sawfly population. *Bracon lisogaster*, a close relative of *B. cephi*, attacks sawfly larvae in the stems of grasses. It can significantly control wheat stem sawfly on native grasslands and roadsides.

Pathogens - Viruses cause disease in wheat stem sawfly

and at times are an important natural control agent. Certain viruses are registered biocontrol agents in Canada for use on a limited number of pests (red-headed pine sawfly and douglas-fir tussock moth).

Damage Assessment

Economic importance

The sawflies are all plant-eaters. Wheat stem sawfly is best known as a pest of wheat and has caused extensive losses to wheat in the northern Great Plains. Its history in Canada dates from 1895 when it damaged wheat near Moose Jaw, Saskatchewan and Souris, Manitoba. Wheat stem sawfly was slow to adapt to cereals but achieved pest status in the 1910s and 20s.

Changes in farming practices have affected the abundance of wheat stem sawfly. Tractor farming increased the relative abundance of wheat and decreased the proportion of oats grown. In addition, as strip farming gained acceptance, sawflies spread easily from stubble and native grasses to wheat. As stubble farming of wheat on wheat stubble increased, so did wheat stem sawfly. Heavy losses occurred primarily in the 1940s and 50s. In 1941 losses totalled 50 million bushels on the Canadian Prairies. Annual losses in Saskatchewan over the period 1926 - 1958 ranged from 1.4 per cent to 10.3 per cent of potential yield. The development of solid-stemmed wheat varieties greatly decreased the importance of this pest.

Damage description

The sawfly larva bores down inside the stem and makes a discoloured tunnel from about the top joint to the root. Sometimes, however, eggs are laid above the top node of the plant and tunnelling by larvae destroy sufficient vascular tissue so that the head turns white.

The greatest losses occur around the margins of fields. Wheat stem sawfly losses are of two types. Larvae feed within the stem of the plant and reduce both yield (a 5 - 15 per cent decrease in total seed weight) and quality of grain (from reduced protein and kernel weight). Larvae cut stems and cause stems to break in the wind, fall to the ground and become unharvestable. These effects of feeding by larvae usually go unnoticed until the plants are toppled by wind and the weight of maturing heads. Mature larvae chew part way through and all around the inside of the stem just before cocoon formation in late summer.

Sampling and monitoring methods

Determine percentage of plants cut by sawfly per square metre prior to harvest.

Economic threshold

Control methods are required if 10-15 per cent of the crop in the previous year was cut by sawfly.

Management Strategy

Effects of weather

Most fluctuations in populations are caused indirectly by weather. The effects of rainfall or drought on the primary food plants, grasses, can be important in determining the size of infestations in the secondary food plants, cereals. When the weather is rainy in the fall or spring, the numbers of large, head-bearing stems of native grasses are adequate for sawfly populations. But when there is a drought, the numbers of grass stems suitable for attack are few and the sawfly concentrates its attack on wheat instead of on grasses. Since only one sawfly will emerge per stem, a shortage of suitable oviposition sites will result in higher mortality due to cannibalism. When rain promotes an abundance of suitable stems, the proportion of stems receiving more than one egg is low and sawfly populations increase. During warm, sunny, windless weather, especially after rain, the sawflies disperse widely. Their attack is otherwise concentrated near the field margins in fewer plants.

Drought conditions can reduce infestations the following year by killing plants that have larvae inside them. Drought in the spring can cause overwintered larvae to re-enter diapause but the influence of this on population size is not clear. Abundant rainfall tends to produce outbreaks of stem rust disease, which is harmful to sawfly larvae. In one instance only 18 per cent of larvae survived in heavily rusted wheat. A population decline in 1955 was attributed to high rainfall and severe rust infestations that killed the larvae in 1954. Doubtless, various fungi cause mortality in the larval population during wet years. Hail, too, can reduce infestations. In one instance there was a small infestation after a severe hailstorm but severe infestations persisted outside the area of hail damage.

Populations build up and damage often occurs at field edges where suitable grass and crop hosts coincide. Wheat stem sawfly is a weak flier and will not take flight readily during cool, rainy or windy weather. Sunny calm weather during the egg-laying period will promote dispersal of wheat stem sawfly.

Weather also affects populations of the parasite, *Bracon cephi*. The parasites are inactive when the grass or crop is wet but become active when conditions are drier. Wet conditions will delay the maturation of host plants. Wet weather may also delay larval development since the larvae apparently require that stem moisture content be under 50 per cent before they will cut the stems. This extended larval period may also prolong exposure to parasite attack.

Cultural practices

A number of practices reduce losses caused by this insect. More than any other practice, the use of resistant varieties has reduced sawfly damage. Sawfly populations have increased in recent years, perhaps because of a neglect (or reluctance) to use resistant varieties, because of a decline in resistance properties of the new varieties, or because of the tendency to use fewer tillage operations. A resurgence in

sawfly populations recently led to losses estimated at over \$5 million in 1990.

Resistant varieties - Lethbridge Research Station has maintained a 'sawfly nursery' for a number of years and since 1987 has evaluated wheat varieties for resistance to wheat stem sawfly. Two sawfly resistant varieties of hard red spring wheat, Lancer and Leader, are currently registered in Canada. Resistance to wheat stem sawfly is closely related to stem solidness and all resistant wheat varieties have solid or semi-solid stems.

Tests of wheat stem sawfly resistance at the Lethbridge Research Station are summarized in the following table.

Percentage of stems cut by wheat stem sawfly

Variety	1987	1988	1989	1990
Hard red spring wheats				
Lancer*	5	1	6	32
Lew*	6	2	19	34
Fortuna*	8	2	10	36
Leader*	13	5	16	35
Glenman*	11	4	25	-
Laura	31	9	29	51
Columbus	22	6	37	54
Katepwa	27	8	34	57
Neepawa	34	10	34	59
Conway	-	-	-	50
Kenyon	-	-	-	51
Prairie spring wheats				
HY320	-	-	-	44
Genesis	-	-	-	50
Biggar	-	-	-	52
Durum wheats				
Sceptre	-	-	-	53
Kyle	-	-	-	63

* Resistant varieties.

Crop rotation - Plant crops that are immune or resistant to wheat stem sawfly. Flax and durum acreage increased after farmers used flax to clear land of sawfly infestations. Durum varieties planted now for sawfly control should have sawfly resistance. Oats is virtually immune to wheat stem sawfly. Larvae rarely survive in barley.

Trap crops - A permanent trap crop of smooth brome grass around a field will reduce the number of larvae that survive in ditches and headlands to. Plants that attract adults are used to collect a sizeable portion of the population. Some control measure is then used to destroy the insects. Susceptible varieties may be used as a trap strip provided the plants are harvested, mowed or cultivated before the larvae move to the base of the plant (before mid-July). Resistant varieties or non-host plants such as oats, brome grass, flax or other broad-leaved crop may be used because females do not fly far from their site of emergence.

Delayed seeding - Delayed seeding in spring produces a

crop that is unattractive to females at egg laying time. Late maturing varieties allow production of two generations of parasites, which results in fewer sawflies the following year.

Summer fallow - Summer fallow infested stubble and then cultivate in early June to bury pupating adults.

Tillage - Shallow tillage in fall increases larval mortality. Deep tillage buries overwintering larvae and reduces adult emergence dramatically but may not be practical because of the potential for soil erosion.

Burning - Burning infested stubble may reduce sawfly numbers but it also greatly reduces parasite numbers and the benefits of returning stubble to the soil. In view of other cultural control options available, burning is not recommended.

Conservation tillage - Continuous cropping of susceptible crops and reduced tillage improve larval survival and therefore increase the risk of infestation. Tillage in late fall and spring reduces sawfly populations harbored in stubble. The less the soil is disturbed, the more sawflies will emerge from the stubble. Conservation tillage and wheat stem sawfly management appears to be incompatible, but producers might consider the benefits of moldboard plowing of small, heavily infested parts of fields.

Swathing - Swath sawfly infested wheat as soon as kernel moisture drops below 40 per cent to save infested stems before they fall.

Delayed planting - Research from Montana indicates that if planting is delayed until May 20th, damage is significantly reduced compared to earlier planting. Yield and quality may suffer if planting is delayed. Accordingly, Montana recommends delayed planting only when sawfly infestation risk is high and a susceptible variety is grown.

Early harvest - Harvest early before sawfly damage occurs and preferably before larvae have moved below the cutting height. Cutting for forage or silage are options. Some standard varieties of wheat may yield better than others when harvested early.

Avoid harmful practices - Do not re-crop infested stubble. Use an alternative crop. Summer fallow badly infested parts of fields. Cultivate summer fallow in early June before adults emerge. Do not plant a susceptible crop on or adjacent to land that was infested in the previous year.

Biological control

Parasitic insects are an important regulator of sawfly populations. Reductions in infestations have been attributed to heavy parasitism in the same or in the immediately preceding years.

Initially, sawflies in grain fields were apparently free of parasites; over time, the number of parasitized sawflies gradually increased. Different parasite species vary in their effects on sawfly populations, depending on whether the infested host plant is in a native or cultivated habitat. One parasite, *B. lisogaster*, prefers larvae in grasses over cereals.

Effective disease control can be attained by several methods. Control may not necessarily eradicate the disease, but rather may decrease the incidence to a level that is no longer economically important. Disease prevention, crop management practices and genetic resistance to the disease must be integrated into a management program to obtain effective disease control. The management program must be tailored for each specific disease, crop, cropping system, location and production level.

Symptoms of Disease

Spot diseases of leaves and stems are usually caused by fungi, bacteria and environmental conditions. Generally, the size, shape and color of the spot is constant for the disease. Stem-eye spot of fescue is an example of a disease that causes distinctive spots on the flowering stems of fescue.

Blotch diseases appear as irregular-shaped leaf lesions. Net blotch is one of the most common foliar diseases of barley in Canada.

Blight fungi typically kill young stems and roots. Seedling blights are common throughout the prairies. In some springs, large numbers of canola fields must be reseeded because of seedling blight. The disease is very active in dry, cold soil conditions.

Scorch occurs during very hot weather. The sun causes a browning or bleaching of leaves. On cereal seedlings, this takes the form of distinct bleached bands called heat banding or rugby stocking.

Wilt results from a deficiency of water in the leaves and stems and is caused by drought or root and stem diseases. Flax wilt is caused by a soil-borne fungus that attacks through the roots.

Damping-off fungi most frequently attack seedlings and kill the stems and roots near the soil line. The disease is active under wet or water-logged soil conditions and causes infected plants to rot and fall over. Alfalfa seedlings are particularly susceptible.

Rots are caused by various organisms. Root rot of canola is a common disease usually caused by *Rhizoctonia*.

Smuts appear as black pustules that break out on the heads of cereals. Loose and covered smuts of barley, wheat and oats are common fungal diseases.

Living (Biotic) Causes of Disease

Infectious crop diseases on the prairies are caused by fungi, bacteria, viruses and occasionally nematodes. Other organisms that cause disease are usually unimportant to northern prairie agriculture.

Fungi

Fungi that feed directly on living plants and cause diseases are called pathogens.

Actively growing fungi in an active stage of growth are composed of very fine hairlike threads growing together in a mat called mycelium. They are familiar as the fluffy growth on rotting food. Fungi reproduce by spores of various shapes, sizes and colors. Spores can be produced directly from the fluffy threads as in the case with bunt balls in wheat. These bunt balls are actually masses of spores. Spores may be formed in or on specialized structures called fruiting bodies. For example, sclerotinia white stem rot of canola produces its spores in tiny mushroom-like structures that grow from black resting structures called sclerotes.

Parasitic fungi are usually limited in the species and even cultivars of plants they attack. Covered smut is a disease of most cereals, but the smut fungi that infect wheat cannot infect barley and vice-versa.

Disease develops when a fungal spore or other infectious agent is able to infect and grow on a healthy plant. The reaction of the plant to the infection is the symptom of the disease.

Spores are the "seeds" in the life cycle of the fungus.

- They are the reproductive structures of the fungus.
- They spread fungi to new locations.
- They survive over winter or other periods of adverse weather.
- Spores are dispersed by air currents, running water, splashing rain, insects, and on or in seeds.

Some fungi, such as *Sclerotinia* and *Claviceps*, produce special resting bodies called sclerotes or ergots. Sclerotes about the size of cereal grains can survive in or on the soil for years. Sclerotia or ergots germinate during moist summer weather and produce tiny mushrooms that release infectious spores. Sclerotinia spores infect canola, sunflowers and beans, whereas ergot spores only infect the flowers of cereals and grasses.

Bacteria

Bacteria are invisible, single-celled organisms. They invade plants through natural openings or wounds. They need free water to enter natural breathing pores on plant leaves and stems. Bacteria can multiply quickly and are most destructive under moist warm conditions. They spread by splashing rain, plant to plant contact, on seeds or by insects.

They cause leaf and head blights, wilts, scabs, cankers and soft rots and overwinter on or in seeds of living plant parts (shoots, buds, crowns) and plant residue.

Viruses

Viruses are visible only under an electron microscope. They are found in all parts of infected plants but usually not in the seed. Many viruses are transmitted by insects such as aphids, leafhoppers and mites. Viruses cannot survive outside the host plant or insect vector. They overwinter in perennial or biennial weeds and in the case of a few viruses, inside seed embryos.

Nematodes

Nematodes are tiny worm-like creatures. They may exist on organic matter in the soil or as parasites of plants. The life cycle of nematodes may take from weeks to months to complete with six growth stages: egg, four larval forms and the adult.

Non-parasitic nematodes are common in prairie soils, but only a few parasitic species are problems in some crops. Stem nematodes may cause yield losses in irrigated alfalfa and cyst nematodes may cause problems in sugar beets.

Nematodes survive in the soil as eggs or cysts that hatch when a suitable host is present. They are spread by humans, wind, water or animals. Nematode distribution may be restricted by quarantine measures as is the case with the golden nematode of potatoes, which occurs in soils on Vancouver Island and Newfoundland. Stringent quarantine measures on the movement of potatoes, other plant parts and soil have prevented this pest from being introduced to the rest of Canada.

Non-Living (Abiotic) Causes of Disease

Soil moisture

Drought is easily recognized. Plants are wilted or dry and dead. A milder moisture deficiency is more difficult to recognize, especially if the plants are also affected by parasitic disease. Water stress weakens plants and makes them more susceptible to infectious diseases.

Excessive soil moisture deprives plant roots of oxygen causing death. Canola seeds in cold wet soil may rot during germination or produce weak yellow seedlings that are susceptible to infectious diseases. Alfalfa roots are sensitive to water logging and are killed by a week of flooding. Grasses may thrive for many weeks under water.

Fluctuation in soil water can cause irregular tillering in cereals.

Soil nutrients

Nitrogen is the most universally deficient nutrient for

crops. Nitrogen deficiency limits chlorophyll development in canola; older leaves turn light green or yellow and wither and fall off. Plants are stunted and the flowering period and seed production are reduced.

Excessive nitrogen can cause heavy vegetative growth. Dense crop canopies are conducive to many diseases and lodging, and both reduce yield and crop quality.

Sulphur deficiency occurs in canola especially on well-drained, sandy and leached Grey Wooded soils. Affected canola leaves are cupped and purplish, flowers are pale yellow, and pods are poorly filled or missing. A deficiency of manganese in organic or alkaline soils can cause gray speck disease of oats and barley. Phosphorous deficiency in cereals will cause reddish or purple leaf discoloration and may predispose wheat seedlings to browning root rot. Copper deficiency in wheat predisposes plants to head discoloration (melanosis), take-all, ergot and low grain yields. Copper is essential for seed production and development in wheat, barley and oats.

Potassium deficiency in canola frequently occurs during cool weather. Although soil tests may indicate that potassium is abundant, this element is not released in a form that is available to plants at a fast enough rate when the soil is cold. This is particularly true during flowering when potassium demand is high. Potassium deficiency in alfalfa is recognized by white spots on the leaves.

Acidic soils below pH 5 may have abnormally high quantities of minerals that interfere with normal plant growth. In addition, calcium needed for normal growth is often lacking in these soils. Alfalfa will not do well in soils below pH 6 because nitrogen fixing bacteria that produce the nodules on the alfalfa roots cannot survive. High pH (alkaline soils) may also limit the availability of certain micro-nutrients. Most crops do best when the soil pH is between 6 and 8.

Meteorologic conditions

Light stress can occur around heavily treed areas. Plants that do not tolerate shade grow tall and spindly and are susceptible to root rots.

Sudden changes in temperature can produce symptoms similar to those of an infectious disease. Blast of oats is caused by extreme heat or very cool weather shortly before the head emerges; seed-producing flowers are killed in the boot stage and no grain is formed.

Heat from the sun is greatest at the soil surface where the tender leaves or young stems of cereals and oilseeds are damaged.

Cold temperatures may damage many crops during the growing season (frost) or over the winter (winterkill). When the growing point of sunflowers or peas is killed by frost, new growth will begin from dormant buds below the damaged area. This results in a distorted appearance or production of an excessive number of branches. Soil surface temperatures of -3 to -5°C for several hours can kill canola

seedlings in May and June. Summer or early fall frosts at temperatures of -1 to -2°C can reduce the quality and quantity of canola and cereal grain. Alfalfa and winter wheat can be killed when soil surface temperatures fall below -20°C.

Typically, wind, hail and lightning cause mechanical damage and make crops more susceptible to infectious diseases.

Toxic emissions or their by-products in the atmosphere can damage plants. For example, ozone in concentrations of more than 80 parts per billion (ppb), which can be produced by severe thunderstorms, may damage field beans. Sulphur dioxide emissions from gas plants, in concentrations of 5 to 10 parts per million (ppm), may injure crop foliage.

Mechanical injuries from almost every agricultural practice done the wrong way, at the wrong time or with the wrong implements can damage plants. Roots can be damaged by cultivation. Rough or improper handling of grain during combining, cleaning or drying can affect seed germination.

Disease Development

For a disease to develop in or on a growing plant, there must be a number of factors in favor of that disease causing organism. These include:

- a susceptible **host**
- a favorable **environment**
- an aggressive and virulent **disease organism**
- sufficient **time** for infection - the longer the exposure time, the greater the probability of infection. For example, six hours of continuous leaf wetness is required before spores of the tan spot fungus can infect healthy wheat leaves.

Non-Chemical Seed Treatment

Hot water treatment

This method must be used with extreme caution because seed is easily injured. The seed is soaked in half-filled loosely woven burlap sacks at 21°C for 5 hours. Remove sacks, drain and place in water bath at 49°C for 1 minute. Move to the next bath at 52°C for 11 minutes. Then place the sacks immediately in cold water. If the seed is to be stored it must be allowed to dry thoroughly. This method is useful for canola seed in breeding programs where seed amounts are small.

Inoculation of legume seed

Legume seed should be inoculated with nitrogen fixing bacteria specific to that species of legume. Alfalfa seed should be inoculated with the bacterium *Rhizobium meliloti*. The bacteria and alfalfa live in a symbiotic relationship; the bacteria fix atmospheric nitrogen in the alfalfa root nodules and exchange it with the plant in return for

nutrients and sugars. Under certain conditions, some soils contain high natural levels of these specific nitrogen-fixing bacteria so that inoculation is not needed every time legume seed is sown. Legume inoculant is particularly important to ensure vigorous stands.

Chemical Seed Treatment

Purpose of seed treatment

Seed treatment provides economical insurance against many diseases and some insect pests of seed and seedlings. Chemical treatment can give seedlings a head start by preventing or reducing damage from certain crop pests.

Diseases are controlled by contact fungicides that destroy fungi carried on the seed, such as common bunt of wheat, the surface-borne smuts of barley and oats, and some leaf-spotting and seed decay fungi. Systemic fungicides destroy fungi carried in the seed, such as loose smut of wheat and barley, and protect the early growth of the seedling.

Specific recommendations are:

- Treat rye and flax to control seed decay.
- Treat winter wheat to prevent bunt and seed decay and promote good seedling growth.
- Treat grain used for seed if bunt or smut was in the field. If a variety is susceptible to bunt or smut and the presence of the disease is uncertain, treat the seed annually or every second year depending on the susceptibility of the variety.
- Treat canola to control the seed-borne phase of blackleg.
- Treat alfalfa seed to control verticillium wilt.

The treatment of cereal and canola seed with fungicides and fungicide-insecticide combinations has increased considerably in recent years. Ninety-five per cent of canola, 70 per cent of barley, 37 per cent of wheat and 27 per cent of oats is treated annually in Alberta. Ninety per cent of some wheat categories such as soft white and prairie spring may be seed treated.

Methods of Seed Treatment

Custom treatment

Fungicides are applied to the seed before planting. Seed cleaning plants are equipped to treat seed with liquid fungicides. Farmers can use a variety of methods for both liquid and dry formulation application.

Drill box treatment

Seed is treated directly in the drill box. Fungicide and seed are layered and then mixed thoroughly. This avoids the problem of storing treated seed or treating more seed than necessary for planting.

Precautions

- Read and follow label directions carefully.
- Do not contaminate grain intended for food, feed or commercial use with treated seed. Bury left-over treated seed or store it safely in labelled bags for future use as seed.
- Treated seed offered for sale must be labelled with the name of the treated chemicals. This is required by the Canada Seed Act.
- Treated seed in transit must be bagged and bulk loads must be covered with a tarp to prevent spillage as required by the Alberta Agricultural Chemicals Act.

Foliar fungicides

In Canada, lower barley prices make application of foliar fungicides feasible only in those areas of high disease potential in regions with high yield or quality expectations. In Western Europe a range of foliar fungicides are used extensively on cereals for disease control. These foliar fungicides may be applied up to three or four times a season on barley (winter and spring types) to maintain yield and grain quality.

Economic consideration

The use of a foliar fungicide on barley should be considered by only those growers living in wetter regions of Alberta who:

- grow barley for pedigreed seed
- produce malting barley
- expect yields over 80 bushels per acre.

Higher foliar disease levels in the barley crop usually coincide with the higher rainfall areas. Fungal diseases such as scald and net blotch will only spread from leaf to leaf during prolonged wet weather. Wet weather conditions or nights with heavy dew from mid-June to mid-July result in the highest incidence of leaf infections. Drought or drying weather during this time results in a lowered incidence of diseases with less effect on yield or quality. In reality, good growing weather is also good disease weather.

General Control Measures for Viruses

- Remove the source of infection. Control volunteers and alternate hosts such as annual or perennial weeds and headlands grasses.
- Use virus-free seed for the control of barley stripe mosaic virus. No other viruses or mycoplasmas are known to be seed-borne in prairie cereals.
- Break the cycle of infection. Do not plant spring wheat next to winter wheat. This breaks the cycle of the wheat streak mosaic virus.
- Change planting dates. Early seeding is usually preferable to avoid late migrations of aphids and mites on the

prairies. The earlier the infection, the greater the yield reduction. Older plants may be more resistant to infection and virus diseases develop more slowly. The best time to plant will depend on the time of migration of the vector.

- Reduce plant spacing. Closer plant spacings tend to reduce infections. Use a planting rate that will provide complete ground cover without reducing yield through competition. Aphids are attracted by yellow and well-spaced plants with open growth habits that expose young yellowish leaves.
- Control aphids and mites, the primary vectors of plant viruses in Alberta. Use insecticides or neutral oil sprays to make plant surfaces unattractive to insect vectors, and non-chemical barriers against infection, such as tall cover crops of sunflowers
- Use immune, resistant or tolerant varieties.
- Prevent long distance spread through quarantine and inspection.

Mycoparasitism

This is a form of biological control where one fungus parasitizes another fungus. However, many fungi that parasitize other fungi under laboratory conditions fail to do so in natural soils. At least two fungi (*Coniothyrium minitans* and *Talaromyces flavus*) have been shown to parasitize the Sclerotinia fungus, the cause of white mold of canola. They occur naturally in the field but their ecological significance and the extent to which they parasitize the white mold fungus is not known.

Interference

Research is underway to investigate the use of interference to protect plants against disease. If the host plant is inoculated with a mild strain of disease or an organism similar to the disease-causing organism, the plant may not be affected by the virulent strain of disease.

The fungus *Phialophora graminicola*, which is closely related to the take-all fungus, colonizes the same place on the roots of wheat but causes no disease. Once colonized by *P. graminicola*, the take-all fungus cannot infect the wheat plant. Mycorrhizal fungi, which occur naturally in the soil in association with plant roots, can act as a protective barrier against infection by *Pythium*, *Phytophthora* and *Fusarium* species. Experiments continue on bacteria such as *Bacillus* species as seed treatments on canola to prevent seedling blight. Presumably the free-living, harmless *Bacillus* species would thrive in the soil and protect canola seed from disease-causing organisms, such as *Rhizoctonia* spp.

Plant diseases are usually less severe on soils with a high organic matter content. This may not only be from increased plant vigor, but there is an antagonistic effect of various other soil micro-organisms that feed on organic matter and become more active.

DISEASES OF CEREALS

ANTHRACNOSE

Colletotrichum graminicola

Biology

Anthracnose attacks cereals and grasses. This disease is not common in Canada, but it does occur on oats in north-central and western Alberta. It infects all parts of the plant.

Spores of this fungus overwinter on the seed and crop residue. Initial infections usually result from soil-borne inoculum. Upper plant parts are usually infected later in the season from spores spread by splashing rain or wind.

Spore production is favored by poor soils, high pH and wet weather. Crops that are nutritionally stressed are especially susceptible.

Damage Description

Brown lens-shaped spots appear on the leaves of oats. Crown and lower stem areas become bleached and then turn brown. Small black dots, which are sexual fruiting bodies, are produced on dead tissue.

Crown infections reduce plant vigor and cause premature ripening. There is also increased lodging caused by constrictions at the base of the tillers. This disease is

generally of little economic significance in the prairie provinces.

Diagnosis

Take representative soil samples at 0-15 cm below ground level throughout the field and have them checked for pH and fertility.

Management Strategy

Reduce spore levels and promote an environment unfavorable to the pathogen.

- Maintain soil fertility with recommended levels of fertilizer and rotations that improve the soil.
- Do not use cereals in crop rotation for at least two years.
- Control grassy weeds as well as headland grasses.
- Turn under crop residue to reduce spore levels.
- Do not grow oats on soils with a high pH.

ASTER YELLOWS

A mycoplasma-like organism (MLO)

Biology

This virus-like disease can attack barley and other crops including canola. The MLO is transmitted by a leafhopper, *Macrostelus fascifrons*. Aster yellows do not occur naturally in field grown oats or wheat but has been transmitted experimentally with leafhoppers. There may be some confusion between the symptoms of aster yellows and barley yellow dwarf.

Each spring, inoculum is brought into western Canada by infected leafhoppers that migrate in from the United States. Barley may also become infected by leafhoppers that overwinter locally and acquire the MLO from infected perennial weeds.

When leafhoppers feed on an infected plant, MLOs are taken up by the insect vector. After 8-10 days, leafhoppers become infectious and can transmit this organism to healthy plants for the remainder of their life span, which lasts up to a few months.

Damage Description

Chlorotic blotches appear on the older leaves, and leaf margins of younger leaves curl under. Blotches coalesce and the entire leaf becomes chlorotic. Plants appear dwarfed and bushy

because internodes are shortened. Heads of infected plants may have distorted awns or floral parts resembling leaves.

Reduced photosynthetic area plus head sterility causes yield reductions. Severity of this disease varies from year to year depending on the size of the population of migrating leafhoppers. The disease is cyclical and only occasionally is of economic significance on barley.

Diagnosis

To positively diagnose this disease a complex procedure involving leafhopper vectors and electron microscopy must be used. However, general symptoms will probably identify the problem.

Management Strategy

Seed crops early. This allows the crop to mature before the MLO can be spread by leafhoppers and cause extensive damage.

BACTERIAL BLIGHT

Barley

bacterial streak and black chaff

Xanthomonas campestris pv. *translucens*

Oats

halo blight — *Pseudomonas syringae* pv. *coronafaciens*

stripe blight — *Pseudomonas syringae* pv. *striaefaciens*

Rye

bacterial blight — *Xanthomonas translucens*

Biology

Bacterial blight, caused by several different species of bacteria, can cause head and foliar diseases of barley, oats, rye and wheat.

The disease-causing bacteria overwinter on crop residue, seed, fall sown cereals and perennial grasses. Spring infection may result from any of these sources. Bacteria are spread by splashing rain drops, plant to plant contact and insects.

The disease is favored by cool, wet weather. Warm dry weather checks bacterial diseases and new emerging leaves may be relatively free of bacterial infection.

Damage Description

Barley

Bacterial streak begins as small pale green spots that become water soaked. These join to form transparent stripes. Later, the stripes turn yellow or brown. A milky exudate may be present on the leaves under wet conditions. When dry, this exudate turns into small thin flakes that are easily removed from the leaf surface. This disease may superficially resemble fungus stripe. However, the fact that all barley plants are uniformly infected in a given location rules out fungus stripe since stripe is seed-borne and is normally scattered throughout the crop.

Oats

Halo blight begins as small light green oval spots with dark water-soaked centres. The spots join to form irregular brown blotches.

Stripe blight produces elongated spots with no pale margins. These spots also have water-soaked centres and turn brown later in the year.

Wheat

Bacterial stripe produces dark green, water-soaked lesions that later turn brown. Near heading, upper leaves develop water-soaked spots that grow to whitish streaks or blotches (white blotch).

Wheat

bacterial stripe and black chaff — *Xanthomonas translucens*

basal glume rot and bacterial black point

Pseudomonas atrofaciens

bacterial leaf blight — *Pseudomonas syringae* pv. *syringae*

Black chaff appears on the kernels as dark stripes on the glumes. These often join and the glumes turn black. These symptoms occur on both wheat and barley. These diseases are sometimes confused with melanosis of wheat that is caused by copper deficiency.

Basal glume rot appears mostly on the inner side of the glumes as a light brown color. As the disease develops, the grain may develop a black spot at the germ end, known as bacterial black point.

Bacterial leaf blight appears on the flag leaf when bright sunny weather follows a rainy period. This disease occurs occasionally on winter wheat.

Rye

The bacterial disease symptoms appear very similar to those described for barley but exudate on the leaves is not as common.

Diagnosis

Plant infections cause a lower photosynthetic area which in turn reduces yield. Kernel discolorations may result in dockage or downgrading of the grain quality. Bacterial blight infestations are usually localized within the field and do not usually cause major field-scale damage.

Bacterial infections in cereals only occur after prolonged periods of wet weather of several weeks or more.

Management Strategy

Avoid infesting clean fields and reduce levels of bacterial infection due to cultural practices.

- Use seed from crops that are free of bacterial disease.
- Do not use cereals in the crop rotation for three or four years. Rye should not follow wheat or rye, and barley should not follow barley.
- Mow infected wild grass along headlands before sowing winter rye.

BARLEY STRIPE, FUNGAL STRIPE

Pyrenophora graminea (asexual *Drechslera graminea*)

Biology

Barley stripe can cause significant yield losses in barley, other cereals are not affected.

This fungus is exclusively seed-borne and overwinters on or in the seed. The fungus grows internally within the infected plant. Spores are produced on the infected leaves and are spread by wind to nearby healthy heads. The seeds become infected only in the field and are most susceptible during early development of the seed head.

Infection of seedlings is higher when soil temperatures remain below 15°C. Sporulation on the foliage of infected plants is encouraged by high humidity.

Damage Description

Vivid longitudinal yellow stripes bounded by the veins appear on the leaves and extend from the base of the leaf to the tip. The stripes eventually become brownish and infected leaves characteristically tear and fray. Infected plants are stunted and heads become twisted, blighted or fail to emerge.

The yield loss is directly proportional to the percentage of infected plants. A 1 per cent infection causes a 0.7 per cent direct yield loss. Some crop compensation occurs from neighboring healthy plants.

Diagnosis

Infected plants are most obvious just before heading out and the disease can be readily identified at this time. After heading out, infected plants may be “lost” under the canopy. Seed samples may be sent out to Agriculture Canada Seed Laboratory in Ottawa to determine the percentage infection.

Management Strategy

- Use disease resistant varieties.
- Avoid infested seed.
- Use a fungicidal seed treatment.

BARLEY STRIPE MOSAIC VIRUS (BSMV)

Biology

Stripe mosaic is a seed-borne virus. In Canada, the virus has occasionally been detected in pedigree seed, but losses caused by BSMV have been rare in recent years. Barley is the main host. On occasions it has been found in wheat and several grass species.

The virus is seed-borne and is transferred from plant to plant when crop leaves rub against one another. Experimentally the virus can be transmitted by pollen, but since barley is self-pollinated this method of spread is generally of no consequence. Infected seeds produce infected plants. Seed from virus-infected plants is generally infected to a 60 per cent level.

Disease builds up when infected seed is planted year after year.

Damage Description

Symptoms may vary with the virulence of the BSMV strain and time of infection. Infections appear as chlorotic mottling with spots or stripes of a yellowish color. Infected plants may be stunted and may mature later than healthy plants.

Yield losses are proportional to the level of infection in the seed lot. Losses are caused by reduced grain production, fewer heads per plant, semi-sterility and incomplete head emergence from the sheath. Heavily infected crops have had yield reductions of up to 25 per cent. The percentage of infected seedlings indicates the level of grain infection.

Diagnosis

For a positive identification of the disease send infected (mosaic symptom) seedlings to your nearest plant disease laboratory along with some seed from the seed lot that was sown.

Management Strategy

Avoid introducing the disease. Montana requires seed from Canada to be certified free of this disease. Seed destined for Montana must be tested at the Montana Seed Laboratory, Montana State University, Bozeman.

- Use virus-free seed.
- Control volunteer barley. Do not plant barley after barley if the previous barley crop was infected.

BARLEY YELLOW DWARF VIRUS, RED LEAF OF OATS

Biology

The barley yellow dwarf virus (BYDV), also called red leaf in oats, can infect barley, oats, rye and wheat as well as numerous species of grasses. It occurs in most parts of the world and is considered the most common viral disease of cereal crops. BYDV is transmitted by several species of aphids and occurs in many strains or types.

Usually the aphid vectors cannot overwinter in Alberta and they normally drift in every spring from the United States. These aphids may already be infective they but can also pick up the virus from infected perennial grasses in Alberta. As the aphids (winged or wingless) feed on the cereal crop, they transmit the virus through their mouth parts. The aphids can remain infectious for life, which is around 40 days.

Damage Description

Symptoms vary with the host species and the stage of crop development. Infections at the seedling stage may result in death or dwarfing as well as sterile heads.

Leaves turn yellow from the tip down along the leaf margins or in blotchy patches. Infected barley leaves, particularly flag leaves, turn bright yellow; in oats, the leaves may turn from red to purple. Discolored areas enlarge and progress to the base of the plant. Heads may be wholly or partially sterile. There may also be an increase or decrease of tillers produced by infected plants. Cereal plants infected early in the season may be shaded out by healthy or late infected surrounding plants. Winter wheat seedlings may be 100 per cent infected with BYDV before freeze-up in the fall.

In dry seasons in the Fort McCleod/Claresholm area, barley that is seeded in June may turn yellow in early July. In alkaline soils this symptom indicates a manganese deficiency in the cereal crop.

BYDV affects yields by stunting, reduced tillering, sterility, and failure to fill kernels. However, because the aphids must move in from the United States, they generally arrive too late in the season to cause significant yield loss in Alberta. In some regions in the United States, yield losses reach 30-50 per cent in oats and 5-30 per cent for barley and wheat. On the Prairies, the only crops that are damaged significantly are late sown spring crops and early sown, fall-seeded crops.

Bright yellow flag leaves in barley by late June or early July will indicate little or no yield contribution from those plants. Severe stunting in winter wheat by mid-May could indicate crop failure from one or more strains of BYDV.

Diagnosis

Visual symptoms will indicate the presence of the disease. Confirmation of this virus must be carried out at a research facility.

Management Strategy

- Use resistant varieties.
- Seed early in the spring. This will allow for maximum growth of the cereal crop before possible infection by migrating aphids.

BLUE DWARF VIRUS, CRINKLE

Biology

This disease is known as blue dwarf virus in barley and oats and crinkle in flax. The virus can only be transmitted by the six-spotted leafhopper (*Macrostelus fascifrons*), which does not usually overwinter in Canada. Each year infective leafhoppers must come in from the United States. Severe outbreaks occur following weather that brings favorable winds which move virus-infected leafhoppers into the prairie provinces early in the spring.

Damage Description

Oats

Early spring infection results in severe stunting. Plants are dark blue-green with short rigid leaves that stand out at right angles. Heads are usually blasted and infected plants may produce new tillers.

Barley

Symptoms are generally similar to oats except that barley plants do not produce new tillers.

Flax

This disease is called crinkle in flax. It results in stunting and reduced tillering.

Diagnosis

Reduced tillering and blasted heads result in yield loss. Mild or suppressed symptoms on many hosts make field diagnosis difficult, therefore BDV may cause significantly more damage than realized.

Management Strategy and Control

Blue dwarf is not usually of significant economic importance in the Prairie Provinces.

Early seeding of cereals and flax in spring allows for more crop growth before infection and consequently less damage.

BROWNING ROOT ROT, PYTHIUM ROOT ROT

Pythium spp.

Biology

All spring and winter cereals along with forage grasses can be infected with browning root rot. The rot is caused by one or more *Pythium* species. This disease was the cause of considerable losses in wheat crops that were grown after fallow in the 1950s. The cause was determined to be low or deficient levels of soil available phosphate.

Fungus spores can remain in the soil and crop residue for five years or more. The spores germinate, invade the roots and cause localized infections. New spores are produced in infected plant parts.

Browning root rot is found in wet soils that have low phosphorus and organic matter levels and a previous history of cereal crops.

Damage Description

This disease occurs in patches. Infected plants become pale green, and lower leaves turn yellow and then brown. Plants are slightly stunted. Diseased plants have fewer tillers, poor root growth and delayed maturity. Soft, wet brown lesions develop on the younger roots near their tips.

Infection during autumn or spring can kill young seedlings but late season infection usually causes a temporary setback, which may not significantly affect yield.

A few isolated diseased areas in a field may be a warning sign of low amounts of organic matter and available phosphorus for cereal crops.

Diagnosis

A soil sample taken according to recommended procedures (that is, cores taken up to 15 cm deep at representative sites in the field) for laboratory analysis will reveal if the phosphorus levels and organic matter content are the cause of the problem.

Management Strategy

- Maintain adequate phosphate levels or balance the nitrogen: phosphate ratio to promote vigorous crop growth.
- Increase organic matter by incorporating straw or manure.

CEPHALOSPORIUM STRIPE

Cephalosporium gramineum

Biology

Winter wheat is the major economic host. Spring cereals and annual grasses (*Bromus*, *Dactylis*, *Poa* spp.) are susceptible but infections rarely build-up to economic levels.

The fungus survives within 8 cm of the soil surface on host residue. Spores germinate and invade roots by way of wounds caused by insects, soil heaving, or other mechanical stresses. The fungus moves through the plant's water-conducting system to the stem nodes and leaves.

Cephalosporium stripe is favored by cool, moist autumns, with fluctuating winter temperatures that result in stop-start growth cycles of the crop.

Damage Description

Diseased plants are usually scattered around the field but may be concentrated in low wet spots. Longitudinal yellow stripes appear through the leaf, leaf-sheath and stem. Veins within the stripe remain green. Stripes become brown and dark areas are formed at the nodes.

Infected plants are stunted and produce white heads. Infection stripes may not appear on all tillers of individually infected plants.

The presence of the fungus inside the cereal stems and leaves interferes with the flow of water and nutrients. Yield losses result from reduced seed production and kernel size.

Infection rates of 80 per cent and yield reductions of 50 per cent have occurred in the United States. In Alberta, this disease is not known to cause significant yield losses.

Management Strategy

- Use a crop rotation of two or three years with legumes, corn, canola or spring cereals.
- Bury infected crop residues more than 8 cm deep.
- Control grassy weeds in the crop and headlands.

COMMON ROOT ROT, SEEDLING BLIGHT, DAMPING-OFF

Cochliobolus sativus, *Fusarium* spp., *Rhizoctonia* spp. *Pythium* spp.

Biology

Common root rot is consistently one of the most damaging diseases of wheat and barley. It can also infect oats, rye and triticale. There are a number of phases to this disease complex; seedling blight, root rot and later in the season, a possible leaf spot phase. The seedling blight phase is less common on wheat than on barley. In the mature plant, root rot caused primarily by *Cochliobolus sativus* is the major cause of crop loss. The leaf spot and head infection phase is less important on the prairies than in the eastern provinces.

Initial infections originate from soil-borne spores.

Seedlings become infected following germination and further infections continue throughout the growing season. Abundant spore production occurs on diseased tissue. Spores are spread by wind, water, cultivation and through infected seeds. Spores may remain viable in soil for several years until stimulated to grow by the presence of a host plant.

Cold soils, as well as drought and high temperature stress are important predisposing factors for an infection.

The strain of *C. sativus* that affects barley is different from the strain that affects wheat. Thus, the severity of root rot may be high in wheat and low in barley in a field where a root-rot susceptible wheat cultivar was grown continuously. The reverse is also true where barley was grown continuously. Thus a crop rotation, even between cereals, will reduce root rot problems.

Damage Description

Patchy emergence is usually the first indication that damage has occurred. Brown spots appear on the roots, subcrown internodes (that part of the plant between the seed and crown) and leaves. Infected plants may be stunted. Seedlings may die before or soon after emergence even though they only show slight damage.

Common root rot and crown damage lower yields. Infected plants tend to produce fewer tillers with smaller and fewer seeds per head. Some plants may ripen prematurely. Root rot in wheat and barley in Alberta causes average annual yield losses of 6 and 10 per cent, respectively.

Cereal crops can withstand a certain amount of seedling blight. The extra space, water, nutrients and light that would have been used by missing seedlings are taken up by neighboring plants to produce more tillers with larger heads and kernels compensating for the loss. No definite threshold levels are available.

Diagnosis

The presence and severity of *C. sativus* on common wheat

can be determined by pulling up plants and examining the crowns and subcrown internodes for disease.

Collect 100 plants, composed of randomly selected groups of 5-10 plants each, and rate the disease level on the crown and subcrown internode by the following scale:

Clean (0)	= no brown spots (lesions)
Slight (a)	= up to 25% of area with lesions
Moderate (b)	= 25-50% of area with lesions
Severe (c)	= more than 50% of area with lesions

Use the formula $\frac{(a + 2b + 4c)}{10}$, where a, b, c are the

number of plants that are rated as slight, moderate and severe, respectively, in the 100 plants sampled. This gives an estimated yield loss as a percentage. Thus, if there were 25 plants in each of the slight, moderate and severe categories, the yield loss estimate equals 17.5%, calculated as follows:

$$\frac{25 + 2(25) + 4(25)}{10} = \frac{25 + 50 + 100}{10} = \frac{175}{10} = 17.5\%$$

A modification of this method only uses two disease categories: clean to slight and moderate to severe. The percentage of plants in the second group is the rating. This multiplied by 0.4 equals the estimated percentages yield reduction. If 40 per cent of the plants are in the moderate to severe category, then the yield loss would equal $0.4 \times 40\%$ or 16%.

These methods may also be used to obtain a disease rating for barley, durum wheat and rye, but no specific data are available for guidance in the conversion factor used to estimate yield loss.

Management Strategy

- Avoid continuous wheat or continuous barley.
- Use rotations with other cereal or non-cereal crops.
- Avoid deep seeding, which reduces plant vigor; a healthy vigorous plant is more likely to avoid or cope with root or crown infections.
- Apply adequate fertilizer especially phosphorus to promote root growth and reduce disease severity.
- Use quality seed that was grown the previous season.
- Turn under of stubble to help reduce infection levels.
- Use resistant varieties.

COPPER DEFICIENCY

Biology

Copper deficiencies can occur in the Black, Gray-Black, Dark Brown, Grey Wooded, peat and transition soils. Wheat, barley, oats, alfalfa and to a lesser extent rye and non-cereal crops can be affected by copper deficiency. This is a non-parasitic disease problem.

Damage Description

Copper deficient plants develop light-green leaves that become dry at the tips. Younger leaves, particularly in barley, may fail to unroll, or may curl, twist and pigtail. Affected roots in wheat and barley are stunted and crowns are excessively branched and rosetted and stems are thin and spindly; elevated levels of take-all or take-all like symptoms may occur in wheat. Heads are bleached and may be incompletely emerged or appear normal but fail to set seed. Ergot may be common in wheat and sometimes barley, and crop lodging is usually more severe.

The heads and stems of copper deficient wheat, especially the variety Park, become melanotic and either shrivelled seed or no seed is produced. Neepawa and other wheats may not show the melanosis typical of Park, but yields can be equally depressed. The melanosis or brown pigment that occurs in some wheats is associated with secondary bacterial infection.

Yield losses result from empty heads, poorly-filled grains and ergot infection. Barley grown in plots deficient in copper will head-out seven to ten days later than barley grown in comparable plots that have adequate available copper; this could be important in seasons with an early killing frost.

Diagnosis

The range between sufficient and deficient levels of copper is quite small. Rye can take copper from soils that are deficient for wheat, barley and oats. Ten per cent or more of the crop land in Alberta may be deficient in copper. Perhaps double this amount of land may have available copper insufficient to allow maximum yield in wheat or barley.

Uneven stands of cereals and the presence of take-all, melanosis and ergot are good indicators of copper deficiency in the field. Specific soil tests for copper availability must be carried out at a soil testing laboratory. Representative soil cores from across the field should be taken at the 0-15 cm and 15-30 cm soil depths. Surface and lower profile copper availability should be over 1 ppm.

Management Strategy

- Apply copper sulphate (bluestone), copper oxychloride or chelated copper to the soil alone or in combination with fertilizer or as a foliar spray. Apply copper compounds as a foliar spray at late tillering. Rates of 10-20 kg of bluestone per acre will correct the low copper availability for 10 to 15 years.
- Grow cereals such as rye or triticale or a non-cereal crop that tolerates lower levels of copper in the soil.

Yield increase (bu/ac) of wheat fertilized with copper compounds

Central Alberta locations-1991

Cultivar	Bear Hills	Millet	Stony Plain
Conway	1	10	17
Katepwa	7	14	13
Kenyon	7	14	-
Laura	7	8	13
Park	4	12	15
Roblin	18	9	19
Oslo	-	-	15
Columbus	-	-	17
Biggar	-	-	32

Yield increase (bu/ac) of oats fertilized with copper compounds-1991

Central Alberta Locations

Cultivar	Millet	Bear Hills
Athabasca	7	0
Calibre	1	2
Cascade	7	4
Derby	8	6
Jasper	22	4
Waldren	8	2

Bushels per acre of barley in 1990 on plots fertilized with 18 kg of copper sulphate per acre in 1987, near Edmonton

Cultivar	Copper	No Copper
Condor	80	26
Duke	113	103
Harrington	85	51
Noble	99	60
Virden	99	52

Original soil tests showed 0.6 to 0.9 ppm available copper.

ERGOT

Claviceps purpurea

Biology

Ergot infects many cereals and grasses; these include in order of decreasing susceptibility, rye, triticale, wheat and barley. Oats are rarely affected.

Ergot overwinters as black grain-sized fungal structures. In late spring, these ergots germinate and form tiny spore-producing mushrooms. Infectious spores are carried by wind currents to the host during the flowering stage. Infection of the cereal flowers may produce a secondary phase called honeydew. Honeydew is a shiny sticky liquid that oozes from infected flowers and contains large numbers of ergot spores. The spores spread to adjacent flowers and heads by insects and rain splash. Ergot that germinates in June can infect early flowering weed grasses, which produce honeydew when cereals are flowering.

Cool, damp weather in late spring and early summer favors ergot germination, helps prolong the flowering period of cereals and grasses and increases the probability of ergot infection.

The presence of ergot in wheat and barley in Alberta has been strongly correlated with soils that are low in copper or with management practices that cause a copper deficiency in cereals. Wheat and probably barley grown on copper deficient soils have a high rate of pollen sterility. Barley and wheat are self-pollinating and the florets normally do not open. If the pollen is sterile, florets of wheat and barley open and expose the stigmas to ergot infection. Male sterile lines of wheat and barley are very susceptible to ergot infection and have been abandoned in plant breeding. Open florets are very obvious in wheat growing on copper deficient soils.

Some herbicides may disrupt copper availability. Manure applications and high application rates of nitrogen and phosphate fertilizer may tie up available copper, particularly on soils already low in this micro-nutrient. All of these factors singly or combined may contribute to copper deficiency resulting in greatly reduced yields and increased infection rates of ergot in barley and wheat.

Damage Description

Ergot is most easily recognized by the hard black bodies that replace the grains of the affected head. Heads may contain one or more ergots. Earlier in the season, before the ergots are produced, an amber liquid or honeydew can be detected on individual flower heads. Heads collect dust and pollen on the sticky honeydew and may appear dirty.

Ergot bodies are highly poisonous. Alkaloids in ergot are extremely toxic to humans and livestock. Ergot alkaloids have been detected in flour and cereals intended for human as well as animal feeds. For cattle,

0.5 per cent by weight of ergot in the diet causes reduced feed consumption and weight loss. Economic losses also result through reduction of yield and through rejection or downgrading of contaminated grain by the elevator. Yields are occasionally reduced by as much as 5 per cent in rye and 10 per cent in wheat.

Diagnosis

The Canadian Seeds Act (July 1987) defines the maximum number of ergots allowed per kilogram of seed before the sample is downgraded.

Grade	Maximum number of ergots/kg		
	Wheat	Barley & oats	Triticale and rye
Canada Foundation #1	1	1	2
#2	8	8	10
Canada Registered #1	1	1	2
#2	8	8	10
Canada Certified #1	1	2	4
#2	8	8	15
Common #1	1	2	4
#2	8	8	15

Ergot can move into a field through contaminated seed but usually the source of inoculum is infested grasses in the headlands. When the disease source is the headland grass the highest density of ergoty cereals is around the perimeter along the headlands. If the infected plants are more evenly distributed throughout the crop, the disease source is likely from contaminated seed or a previously infected crop. Knowledge of the distribution pattern is important at grain harvest. Under very windy conditions in standing grain that is mature or nearly so, the ergots often protruding in infected heads will get shaken or knocked-off. This will reduce by up to 70 per cent or more the amount of ergot in the harvested grain.

Cereal spikes containing ergot have fewer kernels per head with less weight per seed. Yield loss percentage for rye can be estimated as follows:

$$\text{Per cent loss} = \frac{\% \text{ ergoty spikes} \times (1 - \text{seed weight of ergoty spike})}{\text{seed weight of healthy spike}}$$

Management Strategy and Control

Reduce inoculum levels and apply copper fertilizer to reduce or eliminate this disease in wheat and barley. With adequate soil copper, all cereals except rye will have little or no ergot infection. Some herbicides and environmental conditions may interfere with normal growth and reduce available copper and consequently may result in ergot infection. Research in Finland has shown that soils low in

boron induce pollen sterility in barley. Thus in a similar manner to the pollen sterility caused by copper deficiency, the flowers open and ergot infections occur.

- Test soils for copper availability; an application of copper fertilizer may be needed if levels are below 1 ppm.
- Use a rotation with non-host crops to reduce inoculum levels. Ergots rarely survive more than a year in the soil.
- Bury crop residue 2.5 cm or more into soil to prevent spore-producing mushrooms from emerging above ground.
- Delay swathing particularly in headland areas if possible, because windy weather will shake out the ergots from standing grain.
- Mow headland grasses on a regular, annual basis well before seed set. This will prevent ergot production. Meadow foxtail is extremely susceptible to ergot.
- Harvest headland area swaths separately because they are likely to have the highest ergot contamination.
- Store ergoty grain intended for seed for two years. The ergots will die, but the grain will remain viable for many more years.

Ergot in Park wheat, Stony Plain, Alberta***

Treatment	Grain yield bu/ac	Ergots/sq. yd. of crop
No copper*	13	11
Copper**	42	2

*no copper added (DTPA extractable copper 0.6 ppm)

**18 kg of CuSO₄ (4.5 kg actual copper)/acre applied in 1987.

*** Dark grey chernozem

Ergot in Katepawa wheat grown on organic soil, Westlock, Alberta

Treatment	Grain yield bu/ac	Ergots/sq. yd. of crop
No copper*	18	45
6.8 kg CuSO ₄ **	34	2
13.6 kg CuSO ₄ ***	43	1

*no copper added (DTPA extractable copper 0.6 ppm)

** (1.7 kg actual copper)/acre applied in 1989.

*** (3.4 kg actual copper)/acre applied in 1989.

FUSARIUM HEAD BLIGHT, SCAB, PINK MOLD, WHITE HEADS, TOMBSTONE SCAB

Gibberella zeae (asexual *Fusarium graminearum*), *F. avenaceum*, *F. culmorum*, *F. poae*

Biology

This disease affects all grain crops, especially those grown in humid areas. The causal fungi may also incite different diseases on other plant parts. Therefore, head blight may appear with root rot or leaf infections or be the precursor of future seedling blight infections. Wheat planted after corn seems to be particularly prone to this problem because corn residues can produce large quantities of this fungus.

The fungus overwinters in crop residue and grasses. Seedlings may become infected at emergence. Spores are first produced on stem infections at the base of the plant. These spores are spread by rain or wind to infect flower parts, glumes or other portions of the head. This fungus is favored by prolonged warm, moist weather.

Damage Description

The disease is most conspicuous on wheat and barley. Head blight is recognized by premature bleaching of one or all of the spikelets in the head. Infected spikelets are often sterile. The seed in the spikelet stalk above the point of infection may not develop. Diseased heads have small dark spots and fungus growth with an orange to pinkish tinge. Infected grain is shrivelled and lighter in weight with individual kernels usually whitish in color.

Yields are reduced by floret sterility and poor seed filling. A more important factor is the contamination of the grain by mycotoxins. Mycotoxins such as vomitoxin are poiso-

nous, especially to non-ruminant animals. Vomitoxin occurs mainly in soft white winter wheat grown in eastern Canada. Wheat is acceptable for human consumption only when it is virtually free of mycotoxins. Mycotoxins reduce quality and marketability. These losses outweigh yield losses. This disease may be more severe on semi-dwarf and durum wheats than on hard red spring cultivars.

On the prairies vomitoxin usually only occurs in Manitoba grain. There are no records of this toxin in Alberta cereals except for some instances in soft white spring wheats under irrigation. The scab or head blight phase of this disease is fairly common in some years but mycotoxins are absent.

Management Strategy

- Turn under crop residue to reduce inoculum levels.
- Use two- to three-year-crop rotations and avoid cereals and grasses.
- Control barnyard grass and quackgrass, which are also hosts.
- Do not seed wheat into corn stubble.
- Do not seed spring or winter wheat near corn fields infected by fusarium fungi.
- Plant cereal varieties that mature early and escape infection.

GREY SPECK, MANGANESE DEFICIENCY

Biology

Grey speck is a non-parasitic disease caused by manganese deficiency. Soils may be deficient in the micro-nutrient or the manganese may be present in a form unavailable for plant uptake. Grey speck occurs in scattered areas throughout Western Canada. This disease occurs mainly on oats and barley and rarely on wheat.

This condition is associated with neutral to alkali soils that are often high in organic matter. The disease rarely occurs on soils with a pH below 6. Wet, poorly-drained soils cause an increase in disease severity.

Damage Description

The deficiency symptoms appear as brown, unthrifty patches of oats. However, whole fields of barley in southern Alberta may turn yellowish in color. The first indication of the disease is usually seen at the four- to five-leaf stage as light grey oval spots on the leaves, which become irregular in shape and turn light brown. Spots usually appear about halfway down from the leaf tip, sometimes causing the leaf to break over and die.

In southern Alberta, barley that is seeded in July into soils with a pH of 8 may turn yellow or the leaves may become stippled with yellow spots during dry periods. However, with additional moisture new growth may be green and healthy and show no evidence of manganese deficiency.

The degree of yield loss is related to the unavailability of manganese. Grey speck is usually of minor importance but can cause crop failures in some areas. Loss of photosynthetic area and, in some instances, failure to produce heads contribute to yield loss.

Manganese deficiency in cereals at the University of Alberta Farm, Ellerslie (soil pH 6.8)

Variety	% necrotic area 3rd leaf from top, June 30, 1990
Tibor	0
Waldern	2
Terra	2
Cascade	3
Derby	5
Grizzly	13
Riel	20
Foothills	22
Athabasca	22
OT 760	23
Calibre	27
Harmon	28
Jasper	30
OT 768	30
OT 334	33
Robert	43

Diagnosis

Take representative soil samples at 0-15 cm and check them for manganese availability.

Management Strategy

- Use oat varieties known to be tolerant to manganese deficiency.
- Grow wheat and barley, which are less affected by this deficiency.
- Spraying the crop with 1 per cent manganous sulphate will reduce losses, but may not be economically practical.

NET BLOTCH

Pyrenophora teres (asexual *Drechslera teres*)

Biology

Net blotch is a common, destructive foliar disease of barley in western Canada, second only to scald as a cause of yield loss. Net blotch is more common than scald in the warmer drier regions of the prairies.

The fungus overwinters on the seed or crop residue. Spores are produced and spread by wind and rain. Spores produced on infected plants are mainly responsible for destructive secondary spread of the disease within the crop.

Seedling infection is greatest during periods of cool humid weather (10-15° C). Spore production and infection of the growing crop is favored by high relative humidity and temperatures around 20° C.

Damage Description

Light brown spots with distinctive dark brown net-like patterns appear on the leaves, sheaths and glumes. Spots enlarge and join into dark brown stripes. There is also a spot-producing form of this fungus that produces dark brown spots surrounded by a yellow zone. Symptoms vary with the variety and weather.

Yield loss is proportional to the amount of leaf area destroyed on the upper two leaves. The average yield loss in Alberta is about 1.5 per cent. Losses of 50 per cent and more have occurred in highly susceptible varieties such as Elrose. Net blotch lowers grain yield and brewing quality by reducing the carbohydrate content of kernels.

Diagnosis

Use the barley scald assessment procedure to obtain an indication of crop loss.

Management Strategy

- Use resistant cultivars. See appendixes.
- Bury crop residue and destroy volunteers.
- Use balanced applications of nitrogen and phosphorus. Heavy nitrogen applications generally produce conditions favorable to outbreaks of this disease.
- Follow a crop rotation for at least two years with non-susceptible hosts. Barley should not follow barley, particularly if disease levels were high the previous year.
- If barley must be grown in two successive years, use a susceptible cultivar the first year and a resistant type the second.
- Use disease-free seed if possible. Seed may be sent to the Agriculture Canada Seed Laboratory in Ottawa to determine the percentage of infection.
- Control the seed-borne phase of net blotch with a chemical treatment.
- Apply a foliar spray. Tilt (propiconazole) is the only fungicide registered on barley in Canada that is effective for the control of net blotch and scald.

Barley cultivar reaction to scald and net blotch**

		Scald			Net blotch			Field*
		Sus	Int	Res	Sus	Int	Res	ratings
Most susceptible								
Abee	(2-row feed)	X	-	-	X	-	-	4
Deuce	(2-row feed)	X	-	-	X	-	-	3
Jackson	(6-row feed)	X	-	-	X	-	-	1
Otal	(6-row feed)	X	-	-	X	-	-	4
Samson	(6-row semi-dwarf)	X	-	-	X	-	-	5
Condor	(2-row hulless)	X	-	-	X	-	-	7
Tupper	(6-row hulless)	X	-	-	X	-	-	4
Harrington	(2-row malt)	X	-	-	X	-	-	3
Klages	(2-row malt)	X	-	-	X	-	-	5
Ellice	(2-row malt)	X	-	-	X	-	-	5
B1602	(6-row malt)	X	-	-	X	-	-	-
Moderately susceptible								
Galt	(6-row feed)	-	X	-	X	-	-	5
Heartland	(6-row feed)	X	-	-	-	X	-	4
Johnston	(6-row feed)	-	-	X	X	-	-	7
Noble	(6-row feed)	-	X	-	X	-	-	5
Virden	(6-row feed)	X	-	-	-	X	-	7
Duke	(6-row semi-dwarf)	-	-	X	X	-	-	7
Argyle	(6-row malt)	-	X	-	X	-	-	5
Bonanza	(6-row malt)	-	X	-	X	-	-	5
Least susceptible								
AC-Stacey	(6-row feed)	-	-	X	-	X	-	-
Brier	(6-row feed)	-	-	X	-	X	-	-
Leduc	(6-row feed)	-	-	X	-	X	-	8
Winchester	(6-row semi-dwarf)	-	-	X	-	X	-	8

Sus=Susceptible to infection, moderate to severe disease levels. Int=Intermediate susceptibility to light disease levels. Res=Resistant to the disease. These ratings are based on greenhouse tests.

*Overall field disease ratings were established under field conditions at several sites in Alberta. The ratings are on a 1 to 9 scale; 9 is excellent disease resistance and 1 is very poor resistance.

** See the appendix for a more detailed description of disease resistance/susceptibility

POWDERY MILDEW

Erysiphe graminis

Biology

Powdery mildew is one of the most common plant diseases. This disease can be very destructive to wheat and barley and, to a lesser extent, other cereals and grasses. The powdery mildew fungus is made up of different races and forms that are highly specialized, even down to the cultivar of wheat or barley they can attack. Wheat cultivars might be resistant to a certain race of the mildew fungus, but susceptible to another race.

This fungus overwinters on crop residue. Spores are dispersed in early spring by wind and infect susceptible plants. Secondary infections within the crop result from spores produced abundantly on the white mildew that covers the surface of infected plant parts.

Development is rapid in warm humid weather. This fungus is unique in that spore production and infection can take place in the absence of free moisture. Heavy rains are not favorable to spore production or fungal growth over the leaf surface. Rapid growth and dense foliar canopies caused by high nitrogen fertilizer application encourage disease development.

Damage Description

Powdery mildew attacks the leaves, but stems and heads are also affected. The fungus grows primarily on the surface of the host and feeds on the living green cells of the cereal plant. Small, white or gray tufts of spore-producing fungus are most prevalent early in the growing season on the upper surface of the lower leaves. Tissue on the opposite sides of the leaf turns pale green to yellow. The fungal tufts enlarge, join and may turn a reddish brown. Later, this fungal growth

becomes dotted with black pepper-like sexual bodies that enable the fungus to survive between growing seasons.

Damage occurs from reduced photosynthetic ability when green surfaces are shaded and the host is robbed of moisture and food by fungal growth. Yields may be reduced by 20 per cent or more. Cereals affected by mildew produce fewer tillers and grains per head and the grains may be poorly filled. Barley and spring wheat, other than soft white wheat, are seldom affected at economic levels on the prairies. Winter wheat is affected to a greater degree. Considerable losses have occurred in some seasons on soft white wheat. The disease will seriously reduce yields if the flag and second leaf are affected.

Diagnosis

Use the barley scald assessment procedure.

Management Strategy

- Use resistant varieties.
- Follow a crop rotation of at least one to two years, or grow other types of wheat.
- Bury crop residue and destroy volunteer cereals.
- Use balanced applications of nitrogen and phosphorus. Heavy nitrogen applications generally produce conditions favorable to outbreaks of this disease.
- Apply a foliar fungicide.

RUSTS

Barley

stem rust

Puccinia graminis f. sp. *secalis*, *P. graminis* f. sp. *tritici*

leaf rust — *P. hordei*

stripe rust — *P. striiformis*

Oats

stem rust — *P. graminis* f. sp. *avenae*

crown rust — *P. coronata*

Rye

stem rust — *P. graminis* f. sp. *avenae*

crown rust — *P. coronata*

Triticale

stem rust — *P. graminis* f. sp. *tritici*

leaf rust — *P. recondita*

Wheat

stem rust — *P. graminis* f. sp. *tritici*

leaf rust — *P. recondita*

Biology

Many species of rust affect barley, oats, rye, triticale, wheat and grasses. Each rust species includes a number of strains that differ only in their ability to infect certain host crop varieties. Both stem and leaf rust require two different unrelated host species to complete their life cycle. Stripe rust has no known alternate host.

Because the alternate hosts for stem and leaf rust are not

found in Alberta, infectious spores must be blown in from rust-infected crops in the United States. These rust spores directly infect susceptible cereal crops. A single spore pustule on a cereal leaf or stem may produce millions of infectious spores, which can infect other susceptible cereals.

The stripe rust fungus occasionally overwinter in Alberta as the infectious brown spore stage on susceptible winter wheats such as Norstar. Infectious brown spores from

infected winter wheat are able to infect susceptible varieties of soft white wheat earlier in the season, causing considerable damage.

Stem and leaf rusts may cause some infection late in the season, but they are of no consequence in the next year. This is because the brown summer infectious spores die on the crop residue and the black overwinter spores can only infect the alternate hosts, which do not exist in Alberta. The same situation holds true for the destructive QCC race of barley stem rust in Manitoba.

Damage Description

Stem rust

Stem rust produces reddish-brown, elongated pustules on the stems, leaves, glumes, awns and kernels. These contain masses of brown spores. As the plant matures later in the season, the pustules produce black overwinter spores.

Leaf rust

Leaf rust appears as small, round, orange pustules on leaves and leaf sheaths. As the plant matures, the pustules turn dark gray.

Stripe rust

Stripe rust develops as elongated, yellow-orange pustules in rows of varying lengths. This gives the appearance of narrow yellow stripes mainly on the leaves and on the grain heads. These later become dark brown pustules, which produce the overwinter spores.

Crown rust

Crown rust of oats is similar to leaf rust of wheat and barley except the pustules may be present on both sides of the leaves and on the glumes. These are later replaced by black pustules. On the Prairies this disease causes significant

losses only in Manitoba.

Rusts, except for stripe rust which may overwinter on winter wheat, do not usually cause significant yield losses. This is because the rust spores arrive from the eastern prairies too late in the growing season to do much damage, except on susceptible late-seeded and late-tillering crops. Yield losses depend on the crops' growth stage at the time of infection and the amount of leaf tissue destroyed. Early infection of upper leaves, stems, and heads can cause high yield losses in the form of shrivelled grain, reduced baking quality and impaired germination. Serious damage from stem and leaf rust in most years occurs only in Manitoba and sometimes eastern Saskatchewan. Western Saskatchewan and Alberta usually escape losses from these rust diseases in both wheat and barley.

Diagnosis

These diseases can be assessed in the same way as scald of barley.

Management Strategy

Stripe rust

- Use resistant cultivars. There are two types of resistance to stripe rust: seedling resistance and adult plant resistance. Seedling resistance lasts for the life of the plant whereas adult plant resistance only develops between booting and heading. Disease progresses rapidly until adult plant resistance starts, then the advancement of the disease slows dramatically. No licensed varieties have this latter form of resistance.
- Seed early and use early maturing varieties that complete most of their development before being infected.
- Destroy alternate hosts for stem and leaf rusts to reduce inoculum levels.
- Do not plant susceptible spring cultivars near winter wheat fields that may be infected with stripe rust.

SCALD

Rhynchosporium secalis

Biology

Scald is the major foliar disease of barley in the wetter regions of the prairies, particularly the parkland zone of Alberta. This disease can also affect rye and some grasses.

The scald fungus overwinters on barley residue, grain and grasses, particularly species of *Bromus*. In spring, spores are produced mainly from barley residue left on the soil surface from the previous year. Spores produced on infected leaves are transported to other barley plants by rain drops and wind. Scald can attack a barley plant at any time but levels of infection are usually most severe just before and during heading. The significance of scald-infected seed

as a source of disease spread in barley is not well understood.

The disease is favored by cool (12-20°C) humid weather and dense crop canopies where leaves remain wet for prolonged periods.

Damage Description

Scald is primarily a foliar disease but is also found on leaf sheaths and glumes. Large water-soaked, grey-green spots appear on the leaves, rapidly dry out and become bleached with brown margins. Spots often join and kill the entire leaf.

Yield losses in Alberta have been calculated at 2.4 per cent, although losses in particular fields may exceed 25 per cent. Losses are due to a decrease in photosynthetic area on the flag and second leaves resulting in reduced seed weight. Severe scald infections can cause damage that resembles black point but is not confined to the embryo end.

In general there is a direct relationship between the amount of disease present on upper leaves of cereals and the resulting loss in grain yield. The top two leaves of the cereal plant supply most of the energy required to produce well-filled grain. This principal can be used to predict potential yield losses at the milky ripe growth stage.

If scald appears on the upper leaves and sheaths in mid-July, anticipate considerable yield loss. If the scald does not appear until early to mid-August, disease levels may be heavy but actual losses from this disease will be considerably reduced since the grains are well filled by this time.

Diagnosis

Examine the crops at the milky ripe stage (see Feekes scale). Assess no less than 25 main tillers selected at random along two diagonals from one corner to the opposite corner of the field. Assess the percentage of first and second leaves affected. Take the average of the first leaf and

the second leaf and apply it to the following formula. This will give you a reasonable estimate of expected crop loss from scald.

% yield loss =

$$\frac{2/3 \times \% \text{ area of flag leaf infected} + 1/2 \times \% \text{ area of second leaf infected}}{2}$$

Management Strategy

- Turn under or deep till surface barley residue. This reduces disease levels when barley follows barley.
- Seed early with an early maturing variety to miss the major build-up of disease that hits later-sown crops and later maturing varieties.
- Use a crop rotation of at least one year with non-host crops such as other cereals or canola.
- Use resistant cultivars.
- Apply a foliar fungicide.
- Control the seed-borne phase of this disease with a seed treatment.

SEPTORIA COMPLEX, SPECKLED LEAF BLOTCH, GLUME BLOTCH

Leptosphaeria avenaria f. sp. *triticea* (asexual *Septoria avenae* f. sp. *triticea*) *Leptosphaeria nodorum* (asexual *Septoria nodorum*)

Biology

This group of diseases is known as Septoria complex because they all may be present in the same field and even on the same plant. The Septoria complex of diseases occurs mainly on wheat, but is common on barley, oats, rye and grasses, especially *Poa* and *Agrostis* spp. They are widespread throughout the Prairie Provinces.

The fungi overwinter on seeds (*S. nodorum* mainly) and on stubble, straw and leaves of winter wheat. Spores infect the new crop during wet weather. Secondary infection to nearby plants results from spores produced on infected leaf spots transported by splashing rain and wind.

Wet windy weather favors this disease while dry conditions reduce or prevent new infections and spore production on diseased plants. Plants must remain wet for six hours or more for successful spore infection. Increases in the incidence of this disease are related to denser, more humid foliage that occurs with higher nitrogen inputs.

Damage Description

The disease develops on all above-ground plant parts. Yellow flecks generally appear first on lower leaves.

Infections, which are initially water soaked, will become dry, yellow and finally red-brown. Tiny black pepper-like dots (reproductive structures called pycnidia) may appear in the infected areas. *L. nodorum* most often causes blotches on the glumes and stem nodes rather than on the leaves. Infections begin at the glume tips and work downward and form purplish areas that later produce the dark characteristic pycnidia.

Diagnosis

Lesions on the important upper leaves and glumes critically reduce photosynthetic activity and can severely depress yields. Seed set is not harmed but seed filling is impaired and shrivelled grain may be lost with the chaff at harvest.

Management Strategy

- Use a crop rotation with non-cereal crops.
- Turn under the stubble and crop residue to reduce disease incidence and control volunteer wheat seedlings.
- Use seed grown in the drier areas of the province. It may be free of this disease or very low in seed-borne infection.

- Do not use stubble mulching and minimum till. These practices increase the incidence of this disease.
- Use wide row spacing and adequate but not excessive

nitrogen levels. These practices lower canopy density and humidity, which favor infection.

- Use resistant cultivars.

SHARP EYESPOT

Rhizoctonia solani - *R. cerealis*

Biology

Sharp eyespot occurs on the lower stems of cereals and some grasses. Wheat is more susceptible than barley, oats and rye. Winter cereals are more susceptible than spring cereals.

The fungus overwinters on crop residues as a non-spore producing mycelium. The sharp eyespot fungus has a wide host range and infects plants directly through the soil. The eyespot fungus *Pseudocercospora herpotrichioides* causes similar damage on winter wheat in Ontario and was reported for the first time on spring wheat in Alberta in 1990.

Infections can be severe, particularly on light, dry, acid soils during cool springs.

Damage Description

Distinct grey to brown spots with dark margins appear at the base of stems at heading. The spots spread outwards and the centres darken. Dark fungus that can be rubbed off may be present in the centre of the lesion. Stem breakage, white heads and lodging can occur from this disease.

Sharp eyespot can kill tillers or entire plants. Most often this disease reduces size and number of kernels and causes plants to lodge. It also increases the risk of head diseases,

grain sprouting and weed growth.

When disease levels are moderate, affected plants are supported by their healthy neighbors. In severe cases, large areas will lodge. Lodging is non-directional and, unlike crops lodged by wind, does not allow some recovery.

Diagnosis

Check areas of stem breakage for this fungus. Under some conditions, a post-emergence herbicide application may have been responsible for the lower stem breakage.

Management Strategy

Reduce soil-borne fungus levels.

- Use crop rotations with a non-cereal crop or use lower risk cereal crops for two or three years to reduce levels of the fungus in the soil.
- Use management practices such as deep cultivation that shorten residue decomposition time.
- Use wheat types with stiffer straw or solid stems that are better able to withstand stem breakage. There are no resistant cultivars.

SMUTS AND BUNT

Barley

covered smut — *Ustilago hordei*

false loose smut — *U. nigra*

loose smut — *U. nuda*

Oats

covered smut — *U. kolleri*

loose smut — *U. avenae*

Rye

stem smut — *Urocystis occulta*

Triticale

common bunt (stinking smut) — *Tilletia caries*, *T. foetida*

Wheat

loose smut — *Ustilago tritici*

common bunt (stinking smut) — *Tilletia caries*, *T. foetida*

Biology

All cereals are attacked by smut, but each crop is host to specific species of smut fungus. Each smut species has a number of races that differ only in their ability to infect certain cultivars of that crop host.

Covered and false loose smut of barley, bunt of wheat and loose and covered smut of oats will be dealt with as a group because their disease cycle is similar. These fungi overwinter as spores on the seed surface. When infested

seeds are sown, smut spores germinate, penetrate the seedling and grow within the cereal host until the heads develop. Smut fungi replace all or most of the grain head and form masses of black smut spores instead of seeds and chaff. These spores are released at grain harvest and contaminate the surface of other healthy kernels.

True loose smut of barley and wheat differs from the above cycle in that the fungi overwinter within the embryo of the seed. The fungus grows within the plant and produces

loose black smutted heads. Wind-borne, dust-like spores infect healthy cereal flowers, where they penetrate the developing seed and infect the germ (embryo).

True loose smut infection is favored by cool wet weather in July, which slows and prolongs the flowering period and allows more time for infection.

All other smuts are favored by seeding into cold soils during the late fall or early spring.

Damage Description

Most smut fungi attack and replace the internal tissues of the grain with dark brown or black smut spores.

Covered smut (barley, oats)

The plant may be slightly stunted with hard, compact, upright, smutted heads. The smut balls are covered in a membrane that remains intact along with the awns and chaff.

False loose and true loose smut (barley)

These fungi have a very thin covering membrane around the spore masses. The brown spores are blown or washed away and leave bare spikes in the ripening crop. Losses from loose smut in barley average less than 1 per cent, but losses of up to 40 per cent have been recorded. A laboratory examination is needed to tell them apart.

Bunt (wheat and triticale)

Infected heads may be wholly or partially smutted. The heads may remain green longer and glumes in the infected head may be spread apart. Awns may be reduced or fall out as the heads ripen. Bunt balls are rounder than wheat kernels. When these balls rupture, the loose black powdery spores have a distinctive fishy odor.

Smuts attack the grain directly, replace the contents and cause a 1:1 direct yield loss. A 10 per cent bunt infection, if the heads are completely infected, results in a 10 per cent yield loss (aside from quality considerations). The presence of covered and false loose smut and bunt also results in a drastic reduction in grain quality because of the visible contamination with black smut spores.

Smutted grain should be stored separately from clean grain. Heavily smutted or bunted grain will not be accepted at the elevator and may even be difficult to sell as feed owing to respiratory or feed refusal problems that might result. Smuts and bunts are not toxic to livestock.

Economic Threshold

The maximum percentage of smutty barley kernels (true loose smut) permitted under the Canadian Seeds Act, July 1, 1987, are as follows:

Grade	Maximum % of smutty barley kernels
Canada Foundation #1	2
#2	4
Registered #1	2
#2	4
Certified #1	2
#2	4
Common #1	4
#2	6

The fishy odor from bunted wheat is detectable at less than 0.01 per cent thus rendering grain unsuitable for food even at this very low level of contamination.

Diagnosis

Use the following formula to calculate losses from loose smut and bunt in barley, wheat and oats. The percentage of infected ears is directly proportional to grain yield loss.

$$\text{Loss (kg/ha)} = \frac{\text{Pr}}{100 - \text{Pr}} \times \text{Pa}$$

Pr = percentage infected heads

Pa = actual yield (kg/ha)

This is done during heading (Feekes G.S. 10.1-10.5) for loose smut and true loose smut and during ripening (Feekes G.S. 11) for bunt. Assess 50 plants along a diagonal at sites selected at random. Calculate the percentage of infected heads. Thus a 10 per cent infection in a 3000 kg/ha crop = 333 kg/ha yield loss.

Management Strategy

- Use resistant cultivars.
- Use smut free seed.
- In southern Alberta bunt of wheat may be soil-borne. Avoid continuous cropping of winter wheat and do not seed winter wheat within 2 km of a known bunt infected field of either spring or winter wheat because the spores are wind blown.
- Use a hot water seed treatment for loose smut. Dip seeds in 20°C water for 5 hours, drain and then dip in 49°C water for 1 minute, then 52°C water for exactly 11 minutes, then immediately in cold water until seeds cool off. Some seed may be killed by hot water treatment.
- Use systemic seed treatments that contain carbathiin for loose smut control in wheat and barley. All other semi-loose, covered smut and bunts in cereals are controlled by any of the registered fungicide or fungicide combinations.

STEM SMUT

Urocystis occulta

Biology

Stem smut affects only rye and is uncommon except in areas of southern Alberta where the disease has caused significant yield losses on fall rye. This disease is seldom a problem on spring rye.

Spores persist for a year or so in soil, crop residues and on the seed. The fungus infects the fall-sown rye and grows inside the plant. Infected seedlings may die before reaching maturity. The smut fungus produces spores on the top leaves, stems and heads. Spores fall to the ground or are dispersed by the wind onto adjacent land. Spores will contaminate healthy seeds during combining.

The fungus is favored by low soil moisture and temperatures between 10° and 20° C.

Damage Description

Just before heading, long grey-black streaks appear on leaf blades, sheaths, upper stems and heads. Heads may fail to emerge or become distorted and form shepherd's crooks. Infected tillers are stunted and sometimes appear alongside healthy tillers from the same plant.

Infected plants produce little or no grain. In Alberta

between 1977 and 1981, the loss in yield from this one disease was estimated at \$1.25 million per year. The ability of this fungus to survive at least a year in dry soil, failure to use fungicidal seed treatments and the use of susceptible varieties led to the build-up of this disease.

Diagnosis

Infected plants can be identified at the heading out stage. Percentage infection can be calculated by infected tiller counts.

Management Strategy

- Use resistant cultivars.
- Use a crop rotation; include fall rye only once in every three years to avoid soil-borne smut spores.
- Use clean seed from a known disease-free source.
- Do not plant rye adjacent to a previously infected field because the soil could be infested by windblown spores.
- Use a systemic seed treatment that contains carbathiin for control.

TAKE-ALL

Gaeumannomyces graminis

Biology

Take-all is primarily a disease of wheat but barley, oats, rye and a number of grass species can also be affected.

The fungus overwinters on infected crop residue. In spring, the fungus grows in the soil, comes into contact with the crop roots and causes infection. The fungus may grow from root to root infecting new plants. Infection may occur throughout the growing season, but the early infections are the most damaging because they move up into the plant crown. This disease organism is spread by transport of infested soil or crop residue from field to field.

Take-all is favored by cool soils (12-20°C) and high soil moisture. Alkaline soils, compacted, poorly drained soils, and nitrogen- and phosphorus-deficient soils increase disease severity. Elevated levels of take-all and plants with take-all like symptoms have been associated with copper deficient soils. The disease level may be greatly enhanced by some post-emergent foliar herbicide products.

Cultivars such as Roblin and Oslo in particular can exhibit very high levels of take-all or take-all like damage if these herbicides are used on soils that are low or deficient in available copper.

Damage Description

Roots of infected plants are dark brown to shiny black and so rotted that plants can easily be pulled from the ground. Stems may also show this shiny black discoloration. Severely diseased plants are stunted with empty bleached white heads. These white heads stand out in patches in the crop.

Take-all is most severe after wheat is grown in the same field for two to four years. Light infestations may go unnoticed because affected plants show no symptoms, but under severe infestation levels, wheat losses of greater than 60 per cent have occurred.

The disease kills headed-out plants and in spring sown wheat, a 62 per cent infection of take-all reduced yields by 50 per cent. On spring sown barley a 64 per cent infection of take-all reduced yields by 24 per cent. This disease is progressive, spreading from plant to plant throughout the growing season.

Diagnosis

Diseased plants have bleached white heads that pull up easily and crowns and roots that are shiny charcoal black.

Management Strategy

- Rotate crop with non-host crops such as canola, flax or less affected cereal crops. Cereals in order of decreasing susceptibility are wheat, barley, triticale, rye and oats. Planting alfalfa, beans or soybeans in the rotation may not help reduce disease levels. Summer fallow reduces disease incidence in the following wheat crop.
- Maintain adequate nutrient levels, especially phosphorus and potassium. An application of lime on acid soils as well as an application of nitrate to winter wheat in the fall may increase disease severity.
- Control volunteer wheat and grassy weeds that may harbor the fungus.
- Deep till to bury stubble for faster decomposition.

- Do not transport infested soil or crop residue from field to field on equipment.
- Evaluate the effect of post-emergent herbicides. Check those areas in the field that may have missed being sprayed. Is there a difference in the levels of take-all?
- Check soil copper levels; any soil below 1 ppm copper could contribute to take-all severity. Ergot in grain, melanosis in wheat and pigtailed in barley are indications of copper deficiency.
- Treatment of wheat seed with *Pseudomonas fluorescens* bacterial cultures has increased yields up to 10 per cent. Further research is needed to see if this method of control is economically justified.

TAN SPOT, YELLOW LEAF SPOT

Pyrenophora tritici-repentis (asexual - *Drechslera tritici-repentis*)

Biology

Tan spot affects wheat as well as brome and wheat grasses. It occurs in all wheat growing areas of the Prairie Provinces. Rye and barley are rarely affected and oats are resistant.

The fungus overwinters on crop residue and fall sown wheat. Spores produced in early spring are moved by wind to infect other plants. Spores produced on infected leaves become primary sources of disease that are spread during prolonged wet periods. Seedlings may become infected but do not appear diseased until they head out.

Rain and dew encourage spore production and the release of spores from crop residue and existing leaf infections. To become infected, wheat leaves must remain wet for a minimum of six hours. The presence of leaf infections on the winter wheat in May or on spring sown crops in June could result in a rapid disease build-up if prolonged wet weather occurs.

Damage Description

Tan or brown flecks first appear on lower leaves. The flecks become lens-shaped, expand and join. The centres of the spots become dark brown. A zone of bright yellow tissue usually surrounds the dark brown centres. Heavily

infected leaves may wither and die. Infected seed is usually smaller and shrivelled and may have a pinkish coloration.

Yield reductions result from loss of photosynthetic area, especially if flag leaves and heads are infected. Following high levels of disease, kernel weight may be lighter with a possible grade reduction for shrivelled and off-color seeds.

Diagnosis

Use the barley scald assessment procedure.

Management Strategy

- Follow a crop rotation that includes barley and oats, which are not good hosts of this disease or non-host crops such as canola, flax, corn, potatoes and alfalfa.
- Turn under wheat residue. This will reduce the amount of surface straw that can produce air-borne spores during the growing season.
- Do not plant winter wheat on land adjacent to spring wheat that was infected with tan spot.
- Where economically practical, apply Tilt, which is registered for control of this disease. Yield increases up to 15 percent have been recorded.

WHEAT STREAK MOSAIC VIRUS

Biology

Wheat streak mosaic virus attacks barley, corn and some grasses, but is most common on winter and spring wheats. Oats and rye may be infected but they do not appear to be seriously damaged. Mites that transmit this

disease overwinter on winter wheat and occasionally fall rye.

Wheat streak mosaic virus is transmitted by the microscopic wheat curl mite, (*Aceria tulipae*), and mechanically through leaf rubbing. The mite, a relative of the spider

mite, is small, white and cigar-shaped with four sets of legs near the head. It has no wings and is so tiny that it can be blown from field to field by the wind. Both the mite and virus cannot survive without living host plants.

The mite and virus overwinter on winter wheat. In spring, mites multiply rapidly and are blown to other plants. These may be crops of spring wheat or volunteer spring wheat, which then harbor the mite and virus over the summer. If winter wheat is sown near unharvested spring wheat, infective mites can be blown onto winter wheat completing the disease cycle.

Development of this disease depends on the population of mites, the presence of virus-infected wheat plants and sufficient moisture for good plant growth and rapid mite reproduction. Severe outbreaks occur when there is a build-up of mites and virus on volunteer spring wheats in fields next to winter wheat that was planted early. Symptoms of the disease become more pronounced when temperatures climb above 10°C in the spring.

Damage Description

Mites usually first appear at the edges of fields and under favorable conditions move throughout the field.

Winter wheat, although infected in the fall, rarely shows symptoms until spring. These symptoms appear on the leaves as dashes, streaks or yellow stripes parallel to the veins. Leaves become increasingly mottled until the green areas disappear and the plant dies. Infected plants are stunted; the degree of stunting depends on how early infection took place. Wheat spot mosaic virus, which is similar to wheat streak mosaic virus, is spread by mites, has a comparable life cycle, and may sometimes be present in winter wheat.

Wheat infected in the fall or at an early tillering stage stops growing and produces few to no heads. Infection at late tillering to early jointing stages results in head formation but the flowers may be sterile. With late season infection during

jointing to boot stage, the flowers are fertile but kernels are reduced in size.

Fall-infected plants do not produce grain the following season. One study found that stunted and diseased plants yielded 78 per cent less than healthy plants, and seed milling quality was reduced substantially.

Diagnosis

Mites in large populations on wheat will cause the leaf blades to curl upward and inward. Tips of new leaves are often caught in the curled leaf above it; this may indicate the presence of the mites and virus. A microscope or a good magnifying glass is necessary to see the mites.

Management Strategy

Break the life cycle of the wheat curl mite by preventing infection of winter wheat.

- Do not sow winter wheat near immature spring wheat or other cereals. Seed after spring crops mature.
- Control all volunteer host plants at least two weeks before winter wheat is planted; include adjacent fields. The mites cannot survive longer than 10 days in the absence of living cereal plants.
- Plant winter wheat as late in August or September as feasible to avoid the period when mites move from growing spring cereals.
- Do not plant spring cereals, particularly wheat, next to infected winter wheat.
- Control volunteer winter wheat two weeks before spring cereals are sown.
- Do not reseed a severely diseased winter wheat field with spring wheat; diseased winter wheat plants are dif-

WINTER INJURY, WINTER KILL

Cottony snow mold — *Coprinus psychromorbidus* (LTB and SLTB phase)

Gray snow mold — *Typhula incarnata*

Pink snow mold — *Fusarium nivale*

Speckled snow mold — *Typhula ishikariensis* var. *ishikariensis*, *T. ishikariensis* var. *canadensis*

Sclerotinia snow mold — *Myriosclerotinia borealis*

Biology

An important cause of winter wheat damage in Alberta is winter injury or winterkill; these are terms used to describe damage from disease or environmental stress. All cold hardy winter wheat varieties are susceptible to several snow mold fungi. These fungi cause severe damage

under snow cover during conditions that are favorable for disease development. Cottony snow mold fungi are found throughout Alberta, while sclerotinia snow mold is common in the central and northern areas. This fungus can cause damage under snow-covered frozen soil.

When there is little or no snow cover, winter wheat can be

damaged by environmental stresses, including subfreezing temperatures, standing water, ice encasement, heaving and desiccation. In southern Alberta, warm chinook winds may melt the protective snow cover and cause decreased hardiness of plants and expose them to drying winds and frosts.

These fungi overwinter as sclerotes (tiny black structures that are the overwintering bodies) or as a fungus in soil or crop residue. Some fungi, such as *S. borealis*, are an endemic disease of wild grasses. Each snow mold has a specific geographic distribution on the prairies and characteristic environmental factors that favor its growth.

Snow molds cause the most damage when an early snow storm covers unfrozen soil and snow persists throughout the winter, maintaining high humidity and temperatures of about 0°C at soil level. Snow molds grow quite actively at temperatures near freezing.

Damage Description

Because of the complexity of the causal factors, the diagnosis of winter damage is difficult when growth resumes in the spring. Damage is often assessed on the basis of symptoms and a knowledge of the terrain, soil conditions, management practices and weather. Injury from standing water and ice encasement take place in heavy or poorly-drained soils when freeze-thaw cycles and rain occur during the winter. Desiccation injury often occurs on exposed hills and on bare, wind-swept fields. Damage from snow molds is most prevalent and severe following a long, snowy winter, especially where snow has accumulated in drifts. Damage from snow mold may occur in discrete patches, in large areas, or may cause thinning of the stand within the rows.

Winter injury may range from one or two dead tillers per plant to large areas of dead plants within each field. In 1983, snow molds destroyed 80 per cent of the fall rye in the Peace River region.

Diagnosis

Five or more plants per square metre must remain alive to produce an average crop yield. As long as the cereal crowns remain alive, new leaves and roots can be regenerated.

Examine fall seeded crops in April. A quick way to determine if plants are alive is to remove some sample crowns from the field, place them in a closed plastic bag and leave them in a warm room. Crown tissue that is severely damaged will quickly turn brown in a day or so, while healthy tissue remains white.

Management Strategy and Control

Use tolerant varieties and produce an environment unfavorable for the disease organism.

- Cultivars of hard red winter wheat recommended for southern Alberta are more tolerant to ice encasement than those grown elsewhere.
- Do not plant winter wheat too late in the season. Plant resistance to winter injury depends largely on whether enough carbohydrate reserves have accumulated in the crown and whether the plants are fully cold hardened before the onset of winter. The last week of August and the first week of September are considered the ideal planting times.
- Avoid heavy applications of nitrogen in the fall. Use adequate amounts of phosphorus for vigorous root growth.
- Seed into stubble to help trap a light protective cover of snow. Ten centimetres of unpacked snow can prevent soil temperatures from falling below -11°C, even during the coldest periods of winter.
- Seed less than 4 cm deep into a firm moist seedbed.

DISEASES OF OILSEEDS

ASTER YELLOWS

Biology

This disease is a mycoplasma-like organism (MLO) that affects canola, flax and sunflowers. The biology of the disease is similar to the aster yellows described earlier for cereals.

Damage Description

Yield losses result through flower sterility. Infections generally occur at trace levels, and rarely at more than two per cent infection of the crop.

Canola and related crops

Infected plants produce distorted sterile flower heads. Pods are replaced by oval, bladder-like structures that remain green after the rest of the crop ripens.

Flax

Leaves on upper shoots are bright yellow and do not turn brown. Flower parts are leaf-like and greenish-yellow.

Diseased plants may be stunted. Healthy and infected shoots can occur on the same plant.

Sunflower

Aster yellows usually affect only a portion of the head. Flowers grow larger than normal, remain green and do not produce seed. The infected section turns brown and dies. Brown discolorations may extend down the stems and heads may break off.

Diagnosis

Diseased plants are obvious as the crop approaches maturity.

Management Strategy

Seed early to allow the crop to mature to a point where damage caused by the aster yellows organism is minimized.

BLACKLEG, CANKER, DRY ROT

Leptosphaeria maculans (asexual - *Phoma lingam*)

Biology

Virulent blackleg of canola is a fungal canker or dry rot disease of the actively-growing crop that causes stem girdling and lodging. In heavily infested crops, up to 100 per cent of the stems may be infected, resulting in major yield loss.

Two types of blackleg fungus infect canola - avirulent and virulent. The avirulent or mild type has always been common in canola fields. The disease appears on leaves and stems in August but does not usually cause significant damage.

Virulent or severe blackleg infects canola seedlings and progressively damages the growing crop in June and July. It causes major crop losses by severely damaging or killing plants.

When blackleg spores come in contact with growing canola, they infect the live cells of the plant. Both types of blackleg cause dead patches that appear as pepper-like spots on canola leaves, pods and stems. The virulent strain infects canola from germination to maturity, while the avirulent strain is only really active on the ripening crop.

Blackleg is spread by infected seed or by spores that are splashed about by rain or carried by the wind in the

growing crop. Long distance movement of the disease across the prairies is due to infected seed.

Distribution in Alberta

Virulent blackleg was first detected in Alberta in 1983, and is now common in east-central Alberta. Crop losses of 20 to 50 per cent of the expected yield have occurred in fields where a proper rotation was not practised. The disease has been found in several locations in the Peace River region but is uncommon in western and southern Alberta. In general, losses from blackleg in Alberta are minor.

The disease organism, *Leptosphaeria maculans*, occurs world-wide on canola crops. In a 1993 survey for virulent blackleg in Alberta, field infestation levels ranged from nil to a high of 50 per cent in one east central municipality. Blackleg was found in eastern Alberta in canola seed fields surveyed in 1993. Infection were confined to mature leaves, indicating the presence of ascospores.

Damage Description

When blackleg-infected seed is sown, the seedlings that emerge may be infected with lesions on the leaves or stems. These lesions can quickly form spores that remain

infectious for only a few hours and are spread by rain to nearby healthy seedlings to start new infections. In a single season, one infected seedling could spread the infection to many surrounding plants. Thus, a canola crop planted from diseased seed could develop scattered areas of infection all over the field. These blackleg-infected plants result in infected stubble that continues to produce infectious spores (pycnidiospores) for three to five years.

Recently, another kind of spore has appeared in the infected stubble of a few fields in eastern Alberta along the Saskatchewan border. This spore (ascospore) results from the mating of two distinct strains of the virulent blackleg fungus. Both strains have to infect the same plants to hybridize and produce this sexual spore. Ascospores are very common in heavily infested regions of Saskatchewan. Infected canola stubble discharges thousands of these spores into the air from May until October. The spores are wind-borne and can travel several kilometres in the air before landing. If they land on canola or mustard plants in nearby fields, the spores can begin new infections and continue the disease cycle.

The fungus overwinters primarily on canola stubble. The fungus can survive on all canola plant parts, particularly the stems and roots, which resist breakdown in the soil. Canola stubble, especially larger stems, can take two or three years to break down and up to five years during a series of dry seasons. Therefore, infected stubble can continue to produce spores of the blackleg fungus until it is buried and rots in the soil. The heaviest spore production comes from two-year-old infected stubble.

Blackleg can survive crop rotations on volunteer canola. Wild mustards may also harbor blackleg infestations.

Diagnosis

Blackleg is easily detected at flowering and right after swathing. The black stem cankers stand out sharply against the freshly cut stubble.

At flowering select 20 equally spaced spots in a diagonal line across the field. Pull all plants in a 1 ft circle and count all plants; count the number with severely or slightly cankered stem bases. Divide this number by the total number of plants pulled and multiply by 100. Use the following formula to determine the degree of severity of stem canker.

$$\text{Percentage of plants} = \frac{\text{No. of cankered stems}}{\text{total No. of stems}} \times 100$$

Do this again at harvest time, but only count the number of severely cankered stems. Divide by the total number of stems and multiply by 100. Use the following table to estimate maximum yield.

Percentage of plants infected

At flowering	At harvest	Estimated yield (bu/ac)
More than 90	More than 80	13
About 60	About 50	22
Less than 40	Less than 30	27-40

Another method of assessing yield loss caused by blackleg only uses two ratings, healthy or slightly cankered and severely cankered. The percentage of severely cankered plants, sampled at harvest, is calculated and used as a rating of blackleg severity. Yield losses are assessed by collecting 50 plants from each of the two disease classes and weighing the seed in each sample. Percentage yield loss caused by blackleg is obtained using the formula: yield loss

$$(\%) = 100 - \frac{100W}{NW1}$$

W is the total weight of seed from the two samples, W1 is the average weight of seed per plant from the healthy sample, and N is the total number of plants in the sample.

Management Strategy

Prevent the introduction of disease to uninfested areas and reduce inoculum levels where the disease is present.

- Purchase seed that has been tested for blackleg. In Alberta, a laboratory certificate will be issued for all seed lots that were tested for virulent blackleg and shown to be negative for the disease.
- Treat all canola intended for planting with recommended fungicides. Even if seed tests blackleg-negative, there could be a few infected seeds in the seed lot. A fungicide treatment will decrease the chances of blackleg surviving on the seed. Fungicides reduce seed-borne blackleg, but they do not guarantee a 100 per cent control. Do not treat below recommended rates.

A fungicide treatment minimizes the risk of blackleg contamination if blackleg-free seed was accidentally mixed with infected seed during seed cleaning operations.

Recommended treatments also provides protection against other soil-borne diseases and flea beetles.

- Practise a proper crop rotation. Do not grow canola on a field more often than once every four years. There is always a possibility that blackleg could be introduced to your land by wind-borne spores; longer rotations will increase the probability that low levels of disease infection will disappear when the infected stubble has rotted.
- Practise good weed control, particularly volunteer canola.

Blackleg can live from one year to the next on volunteer canola and wild mustards. If you do not practise weed control and eliminate volunteer canola and mustards, a long crop rotation will be ineffective.

The following procedures must be adopted for control of blackleg on infested land:

- Bury canola stubble as deeply as possible in the fall. Alternatively, where soil erosion is a problem, incorporate the canola stubble just before planting. This practice speeds stubble decomposition and reduces the disease infection potential in the field.

- In the following three seasons, use shallow tillage or direct seeding to avoid bringing infected canola residue to the surface. Additionally, plant non-host crops such as cereals, grasses, alfalfa, clover and pulses.
 - If possible, do not plant canola closer than one kilometre from infested land for three years.
 - Keep infested land free of volunteer canola and wild mustards. You may have difficulty controlling volunteer canola in newly seeded alfalfa, clover and peas.
 - Do not plant canola seed from infested land.
- See appendix at end of book for recommended varieties.

BLACKSPOT, ALTERNARIA BLACK SPOT, GREY LEAF SPOT

Alternaria brassicae, *A. raphani*

Biology

These fungi occur every year in canola growing areas. The disease is most common in the shorter season and higher rainfall areas such as the Peace River and west-central regions of Alberta. The disease is most harmful to the Polish cultivars that are usually grown in these regions.

These fungi usually overwinter on infected crop residue and on the seed. It is not uncommon in northern Alberta to have seed lots that are infested at a level of 20 per cent or more. Seed formed below a pod spot caused by this disease will become infected.

Warm, humid conditions favor disease development.

Damage Description

Infected seedlings have dark spots on the cotyledons and first true leaves. Leaf spots range from grey to black depending on environmental conditions. Stem and pod lesions are small brownish-black dots, later becoming black or grey with a dark border. Infected pods may ripen prematurely and shatter while the crop is standing or in the swath.

Pod infections result in shattering and shrunken infected seeds. Yield losses of 25 per cent or more may result from the shattering.

Diagnosis

Check the amount of infection in the late green pod stage. Infected area refers to the amount of pod surface area covered with black dots. Each one per cent of stem and pod surface infected represents a one per cent yield loss.

Management Strategy

Prevent disease introduction and minimize losses through early swathing.

- Rotate with non-cruciferous crops.
- Control volunteer canola and cruciferous weeds in the rotation.
- Clean the seed to remove shrivelled infected seeds.
- Purchase seed from the drier regions of the prairies that may carry less disease, but do not buy seed from areas where blackleg is endemic.
- Swath as early as possible to reduce losses from shattering.
- Plant Argentine cultivars, which are more resistant than Polish ones.

CLUBROOT

Plasmodiophora brassica

Biology

Clubroot affects all members of the (cabbage) crucifer family. This disease has not yet become a concern in canola growing areas of the Prairie Provinces, but is a problem in southern British Columbia and Eastern Canada.

Resting spores of this fungus can survive in the soil for five or more years. These resting spores germinate in the presence of host roots to produce tiny mobile spores that can swim in the soil moisture. The spores enter the rootlets and multiply in the host cells. Infection causes the roots to produce galls or clubs characteristic of this disease. Resting spores formed in these clubs are released

into the soil when the roots rot away. There are many strains of the disease organism, which vary in their ability to attack the different species of the crucifer family.

For resting spores to germinate, the soil pH must be below 7.2 and soil moisture must be 50 per cent above water holding capacity.

Damage Description

Infected roots produce galls ranging in size from tiny nodules to large club root overgrowths that may involve the entire root system. Galls first appear white and firm but become soft and brown as they mature and rot. Above

ground symptoms are wilting during warm weather and stunting of affected plants.

Diseased roots are unable to transport food and water. Galls (clubs) allow other root rotting organisms to infect the root system. Swollen lower stems on some canola cultivars are referred to as hybridization nodules. These nodules are common in rutabagus and turnips and are non-infectious. Very low levels of 2,4-D or related herbicides may induce a swelling of the upper root region of canola plants that superficially resemble club root.

The potential for damage to Polish canola is high, particularly in acidic soils.

The clubroot organism has been found in a few locations on the prairies in backyard crops (cauliflower, cabbage).

Management Strategy

Do not introduce the disease organism.

- Seed into soil free of the clubroot organism.
- Do not use machinery from infested fields because resting spores can be carried in soil.
- Do not allow irrigation or drainage from infested fields to contaminate clean areas.

- The clubroot organism can survive passage through digestive tracts of farm animals. Feeding clubroot infested turnips to cattle can result in spread of the organism through manure.
- Use resistant varieties. The clubroot organism exists in a large number of strains some of which may or may not attack canola varieties. For example, the Polish variety Candle is highly susceptible to race 6 of the clubroot organism, whereas Altex, an Argentine variety, is relatively immune.
- Use a long crop rotation with non-cruciferous crops (seven years) because spores can survive for a considerable time.
- Control cruciferous weeds in the rotation.
- Provide drainage to reduce soil moisture. Wet soils favor the clubroot disease.
- Provide adequate nutrient levels. Crops are less susceptible to clubroot damage if they are growing vigorously.
- Lime the soil. Raise the soil pH above 7.2 if feasible.

DOWNY MILDEW, ANGULAR LEAF SPOT

Peronospora parasitica

Biology

This disease affects canola and sunflowers and usually occurs with staghead (white rust). Downy mildew can also infect seedlings and leaves of *Brassica rapa* CB. *campestris*.

The fungus overwinters on stagheads and crop residue. In the spring, spores germinate and infect leaves and newly formed stagheads.

This disease is favored by cool wet spring weather.

Damage Description

The fungus appears as a white mealy growth on the lower surface of leaves and green stagheads. The upper leaf surface turns yellow.

This disease by itself is of little economic significance. The combination of downy mildew and white rust has more yield-damaging potential.

Diagnosis

Examine the crop in the late rosette stage during cool, wet overcast weather.

Management Strategy

Reduce inoculum levels.

- Use a crop rotation with non-cruciferous crops.
- Control volunteer canola, stinkweed and wild mustard.

FROST AND HEAT CANKER OF FLAX

Biology

Heat and frost canker of flax occurs under excessively high or low temperatures at the soil surface. The seedling is injured when young plant tissue comes into contact with soil or air at temperature extremes. In cereals, this is called heat and frost banding or rugby stocking.

Damage Description

In young plants, stems become constricted at soil level, collapse or break-off. In older plants, a canker is formed, which breaks when the standing crop is exposed to strong winds.

Direct loss of yield occurs as a result of the death of plants. Damage may be confined to small patches or scattered throughout the field, but losses up to 50 per cent have occurred. Damage is usually most severe in thin stands on light soils.

Diagnosis

Check for damage during periods of weather extremes.

Management Strategy

Avoid heat stress and prepare plants for stress.

- Sow early in a north-south direction at a high rate. This reduces heat canker by providing maximum shade for each plant.
- Prepare a proper seedbed. This will prevent damage from heat and frost canker by promoting even and vigorous stands that can better withstand temperature extremes.

FUSARIUM WILT

Fusarium oxysporum f. sp. *lini*

Biology

Fusarium wilt of flax is both seed and soil-borne. The fungus lives on flax residue but both the fungus and spores can survive a number of years in the absence of flax. The fungus invades the plant roots and causes wilting.

Infection may occur in cool soils but warm soils are favored for disease development.

Damage Description

Seedlings may die before or shortly after emergence and older plants may stop growing at any stage of development. Later infections cause plants to turn yellow, leaves and stems wilt, and then plants turn brown and die. Diseased roots turn grey. Wilted stems often curve downward in a shepherd's-crook shape. Affected plants commonly occur in patches in the field.

Direct yield losses result through death of plants.

For many years, flax was only grown on newly broken land because yields were greatly reduced in soils that were cropped repeatedly, becoming "flax sick". This disease commonly occurs every year in flax growing areas but causes little damage due to resistant cultivars.

Management Strategy

- Use resistant cultivars.
- Follow a crop rotation of three years with cereals, canola or grasses.
- Use disease free seed.
- Use a recommended seed treatment to control seed-borne inoculum and reduce the chances of introducing the disease into new areas.

GREY MOLD HEAD ROT

Botrytis cinerea, *Rhizopus* sp.

Biology

Grey mold head rot is a fungal disease of sunflowers. These fungi overwinter in crop residue as tiny hard black overwinter bodies (sclerotes). The sclerotes germinate and produce spores that infect the heads of sunflowers. Moisture trapped on the backs of sunflower heads that are hanging downwards provides ideal conditions for infection.

Cool temperatures (18-23°C) are required for disease development; damp conditions are necessary for germination, spore production and infection. Gray mold head rot caused by *B. cinerea* typically occurs on maturing plants during wet weather in the fall. *Rhizopus* (a bread mold fungus) infections are encouraged by injuries from hail, insects and birds.

Damage Description

Botrytis cinerea

A brown area appears on the back of the head and soft rot develops. Infested areas become grey with surface fungal growth. Seeds may be contaminated.

Rhizopus species

Irregular, water-soaked spots appear on the back of heads; these enlarge and turn brown, until the whole head is soft and pulpy. Masses of surface-borne fungi with visible, stalked, black spore-producing structures are present. This fungus can invade the seed.

Losses result from reduced seed yields. Contaminated seeds may seriously affect the following years' crop establishment and yield due to seedling blight or poor germination.

Diagnosis

In a cross section of the crop inspect the flower heads as they approach maturity.

Management Strategy

- Use a crop rotation of three or more years.
- Turn under crop residues.
- Avoid harvesting delays if at all possible.

GREY STEM, WHITE LEAF SPOT

Pseudocercospora capsellae

Biology

Grey stem of canola is found in all canola-growing areas of the Prairie Provinces. It is usually most conspicuous just after swathing, but causes little yield loss.

This fungus overwinters as mycelium in the canola residue. In the spring, spores are produced that infect canola plants and form white leaf spots. The disease generally spreads rapidly only after the canola seed is fully developed and the crop has reached maturity.

Plants under stress from drought, low fertility or competition by weeds are likely to be more adversely affected by this disease.

as plants mature, grey to purple speckled patches appear on the stems and pods.

Because this disease affects plants as they are maturing, little significant yield loss results.

This disease is conspicuous after swathing.

Management Strategy

- Use a crop rotation with non-host crops.
- Control volunteer canola and related crucifers.
- Use good crop production techniques that reduce plant stress.
- Plant Argentine (*Brassica napus*) varieties which are less affected than Polish (*B. rapa*) varieties.

Damage Description

In the summer, white leaf spots appear on the leaves. Later

PASMO

Septoria linicola

Biology

Pasmo attacks all above ground parts of flax.

This fungus overwinters on diseased flax residue. Infested seeds, chaff and residue can be mixed together in a seed lot. Spores are spread to growing plants by wind and rain. Under suitable moist weather conditions, disease spread is extremely rapid.

The disease is favored by warm moist conditions.

crop is left to be straight combined, and strong winds and heavy rains cause bolls to break-off.

Diagnosis

In Alberta, this disease usually occurs late in the season and causes light damage to the crop.

Damage Description

Symptoms first appear as brown spots on the leaves. As the disease progresses, infected leaves may drop off. Brown spots appear at the leaf-stem joints. These spots eventually circle the stem, giving rise to a mottled appearance of alternating bands of brown and green. Flax flowers and bolls may be blighted or discolored.

Early infections can greatly reduce yield and quality of seed and fibre. Premature ripening and poorly-filled seed result from early infections. Heavy losses occur when the

Management Strategy

- Use a crop rotation. Flax crops should be grown several years apart. Do not plant flax near fields previously seeded to flax.
- Use clean seed. Clean out any crop residue from the seed that might be infected.
- Plant as early as possible to escape disease build-up before crop maturity.
- Use a recommended seed treatment.

ROOT ROT, BROWN GIRDLING ROOT ROT, ROOT ROT COMPLEX

Rhizoctonia solani

Biology

Root rot or brown girdling root rot is quite different from blackleg and other stem and root rots of canola because it remains confined to the roots and does not appear above the soil line.

Rhizoctonia is a soil-borne organism. When canola roots are infected by this fungus, it grows into the root. Following infection, the fungus may grow slowly in the roots. When conditions are favorable disease symptoms typical of root rot appear. This fungus can infect canola roots at any growth stage. When seedlings are attacked and die, the disease is called seedling blight. In the fall, dormant resting bodies are formed by the fungus that will germinate in subsequent years and continue the cycle. There are many strains of the *R. solani* fungus that vary in the severity of infection towards canola. They are referred to as anastomosing groups (AG), that is, compatibility groups. Thus AG-2 and AG-4 were the only groups isolated by S.F. Hwang and co-researchers from canola fields in Alberta. In virulence tests AG-2 were much more pathogenic to canola than AG-4. Other AG groups of *Rhizoctonia* that attack potatoes and flax are normally non-pathogenic or weakly pathogenic to canola.

High soil moisture, fine-textured soils with a high clay content, high copper levels (4-20 ppm) and soils with poor or unbalanced fertility favor this disease.

Damage Description

Above ground plant parts wilt and lodge. Light brown areas may appear on any part of the root. These areas may expand and girdle the root, become dark brown and sunken and rot the tap root away. Plants may fall over or remain standing, wilt, dry up and die.

Direct yield loss is proportional to the amount of root system lost by girdling. Losses result from increased pod sterility, reduced seed weight, seed shrivelling and plant death. There is also an indirect loss from shattering when plants prematurely ripen, and an increase in senescence-type diseases such as grey stem. Yield losses of up to 55 per cent in

individual fields have occurred, although average losses range from 8-18 per cent depending on the season.

Diagnosis

At mid-flowering stage, dig up 10 plants from each of 10 spots (100 plants). Wash the collected roots and examine for brown lesions. If only root stubs are present or the tap roots are girdled by brown lesions, the disease will result in considerable yield loss. If brown spots are present, but do not girdle the root, actual disease losses may be minimal.

Management Strategy

Maintain conditions unfavorable to the disease-causing fungus, use resistant cultivars and avoid disease build-up.

- Use Argentine canola (*Brassica napus*) varieties when the growing season allows because they are much less susceptible to this disease.
- Do not plant canola into heavy clay soils if possible.
- Maintain recommended N, P and S fertility levels in the soil. The addition of lime will reduce soil copper availability levels, which may be a factor in this disease.
- Follow a crop rotation of three to four years using cereal crops. Do not plant canola after canola or canola after fescue. Decomposing fescue sod, for reasons not clear, is conducive to the development of this disease.
- Control volunteer canola and cruciferous weeds especially stinkweed, shepherd's purse and ball mustard, all of which can serve as hosts for the fungus.
- Seed shallow and plant into warm moist soil. This may reduce seedling blight and root rot.
- Use a recommended seed treatment to control the seedling blight stage of this disease.
- See appendix at end of book for recommended varieties.

RUST

Melampsora lini

Biology

This rust affects both oilseed and fibre flax. This disease is different from cereal rust in that an alternate host is not required. The entire life cycle, including the sexual cycle, occurs on the flax plant. From the sexual cycle, new races of the disease are constantly evolving. A flax variety that was resistant a few years ago may now be susceptible to a newly-developed race of the rust fungus.

Spores overwinter on the crop residue. These germinate and produce small spores that infect the seedling flax leaves. Orange-yellow pustules form and produce large quantities of summer spores that can infect surrounding plants. As the crop matures, the pustules turn a dark brown to form the overwintering spores.

This disease is favored by warm, humid or wet conditions.

Damage Description

In June, pustules containing yellow spores appear on the undersides of the leaves. Later, larger powdery orange-yellow pustules appear on leaves, stems and heads. As the plant matures, pustules form dark brown spores. These dark brown pustules develop on the stems and bolls, but rarely on the leaves. Pustules in the black spore stage are often large and extend vertically for several centimetres and girdle the stem.

Flax rust may completely defoliate plants and cause reduced vigor, yield, and quality of seed and fibre. Stem breakage can also occur.

Diagnosis

Orange pustules on the seedling crop can mean, under favorable weather conditions, a severe disease outbreak may occur and cause significant yield loss.

Examine the undersides of seedling leaves, particularly if the rust disease has been on your land in previous years.

Management Strategy

- Use resistant varieties.
Resistant Cultivars: Andro, Dufferin, Linott, MacGregor, NorLin, Somme, Vimy.
Susceptible: Noralta, Redwood 65
- Use clean seed and remove any infested crop residue that might carry spores.
- Follow a crop rotation. Do not plant flax on flax stubble. Plant flax as far from last year's flax crop as possible.
- Control volunteer flax.
- Plant as early as possible to help the crop mature before rust build-up becomes serious.
- Bury flax straw to enhance decomposition and reduce rotation time.
- Use a recommended fungicide to control any rust spores on flax residue or seed. This will help prevent introduction of new races of the fungus to areas free of them.

SCLEROTINIA, STEM ROT, SCLEROTINIA WILT, HEAD ROT

Sclerotinia sclerotiorum

Biology

These very different diseases are caused by the same fungus. Sclerotinia wilt in sunflowers is caused by a below-ground root infection of the fungus, while stem rot of canola and head rot of sunflowers result from air-borne spores. This fungus can attack a wide range of broad-leaved plants including many crops and common weeds.

Although the fungus is the same, the disease cycles for canola and sunflowers are quite different.

Canola

The fungus overwinters as sclerotes, which are hard black structures that germinate in early summer and produce small spore-producing mushrooms (apothecia). Minute infectious spores are produced in huge numbers and some land on stems and leaves of the flowering canola crop. Flower petals are necessary as a food source for these spores to grow after germination. Mid- to late-flowering, when large quantities of fallen petals are present, is the most critical stage for infection of canola plants. After growing on the petal, the fungus acquires enough energy to attack living canola plant leaves or stems. A typical white stem rot infection is the consequences. In severe disease outbreaks, the seed pods may be infected. Later, hard black sclerotes are produced inside (sometimes outside) the diseased stems and pods. These are released during harvest operations to infest

harvested seed or soil. The soil-borne sclerotes may survive for many years before suitable conditions allow them to germinate, form mushrooms and continue the life cycle of this fungal disease.

Sunflower

Plants are mainly infected by mycelium that grows directly from buried sclerotes into the roots. Infected plants wilt and die. Sclerotes are produced in or on the diseased stems and roots. Head rot results from infection by air-borne spores similar to stem rot of canola. Root infection does not take place in canola or mustard even though sclerotes can germinate freely in the soil to form mycelium rather than spore-producing mushrooms.

Warm moist soil conditions are required for sclerotes to germinate and form the spore-producing mushrooms (apothecia). Mushrooms can be produced by sclerotes at the soil surface or buried as deep as 7 cm in the soil. Humid weather or heavy dews are required for spore infection when crops are in flower. Heavy yielding canola crops with dense canopies that maintain humid air conditions are most likely to become infected with this disease. Under drier conditions, where the absence of surface moisture makes it unsuitable for sclerotial spore production, root infection will show up only in sunflowers. Root infections that cause sunflower to wilt can occur much earlier in the season than aerial spore infection of canola.

Other oilseed crops

This fungus will occasionally infect flax and frequently damage safflower in much the same way that sunflowers are attacked.

Damage Description

Sunflower wilt

This disease can spread along the row by plant to plant root contact. Leaves of infected plants wilt within a few days. Root systems rot and the lower stem develops a wet canker covered with white fungus. Stems become shredded and straw-like. Sclerotes are produced on the inside and outside of the infected area. Head rot starts as a light brown, water-soaked area on the outside of a developing flower head. The rot may partially or destroy the head. White fungus and sclerotes are usually abundant. In severe cases, the head rots and falls off and the straw-colored stem remains standing.

In Canada, attempts to control *Sclerotinia sclerotiorum* wilt of sunflowers and white mold of beans using mycoparasites (that is, fungi that can attack sclerotinia) have met with some success. The fungi, *Coniothyrium minitans*, *Gladiolus catenulatus* and *Trichoderma viridae* were all able to infect and kill sclerotes of this fungus in the soil and thus reduce the sclerote population. All three fungi, however, were ineffective in controlling *Sclerotinia* in an active growing state and have thus failed to reduce the spread of this disease. Further research needs to be done in this area of biological disease control.

Canola

Infections begin as soft watery rots on leaves and stems, especially at the leaf axils. When the rot girdles the stem, the plant dies. The dried infected areas often have zonate markings. Diseased plants become straw colored and later stems bleach white and shred. Generally the fungus produces the typical hard black sclerotia in the hollow centres of diseased stems.

Severe losses result when weather conditions suitable for infection occur at mid-flowering. These losses range up to 50 per cent or more. Yield losses can be attributed to smaller and fewer seeds, premature ripening, shattered pods and the loss of smaller, shrunken seeds during combining. The presence of fungal sclerotes in the combined seed is also undesirable. Some countries have a zero tolerance for the presence of sclerotes in imported grain.

Yield losses equal about 50 per cent of the main stem infections. A field with a 50 per cent main stem infection would have an approximate yield loss of 25 per cent: $50 \times 0.50 = 25$. The actual yield losses depend on the variety, weather and time of infection. Thus a 40 bu/acre crop with a 50 per cent infection level would give a yield loss of 10 bu/acre.

Some three million acres of canola are grown annually in

Alberta. In a 1983 survey of Alberta growers, 35 per cent of the growers reported sclerotinia problems, with one half of them (18 per cent) reporting moderate to heavy damage.

Diagnosis - Canola

A disease forecast system helps canola growers predict outbreaks of sclerotinia white stem rot. The forecast system is a checklist that assists growers to make a decision on the need to apply a foliar fungicide.

Because the fungicide must be applied before symptoms of stem rot are visible, at the 25-30 per cent bloom stage of the crop, a grower must attempt to determine the economics of a fungicide application. This checklist is not always reliable because sudden weather changes can cause infestations to occur unexpectedly or high risk fields may show limited disease development. However, this checklist gives practical direction in making the decision to apply fungicide.

Bloom stage identification

If you plan to apply fungicide for sclerotinia control, you must decide when to spray. Sample several plants over the field and assess the number of open flowers. One way to check for bloom stage is to find the main stem, pull off the secondary branches, and count only the open flowers on the main stem. Generally, it takes a crop from two to four days to move from first flower to 10 per cent bloom.

Identification of the flower stages of canola

Flower stage	Argentine (flowers-main stem)	Polish (flowers-main stem)
10%	10	6-7
20%	14-16	10-12
30%	20	14-16

At 30 per cent bloom, a field of canola is said to be fully flowered, when the maximum number of flowers are open at one time when the crop is at its yellowest.

Sclerote contamination of seed

These levels were obtained from the Canada Seeds Act July 1, 1987.

Grade		Maximum % of sclerotes/ kg	
		Canola	Sunflower
Canada Foundation	#1	1	1
	#2	2	8
Registered	#1	1	1
	#2	2	8
Certified	#1	1	1
	#2	2	8
Common	#1	2	4
	#2	-	8

Sclerotinia petal test kit

The petal test kit consists of two parts each sold separately. Part 1 is a 25 page manual with a videotape and forceps. Part 2, for testing one field only, consists of culture plates, dishes and disinfectant. These kits may be purchased from the Department of Biology, (Petal Test Kits), University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W0. Purchases of these kits must be confirmed before May 15 of the crop year. The petal test method may be no more accurate than the "Sclerotinia Stem Rot Checklist" because many of the same factors apply. What this kit does is give canola producers a hands-on understanding of the sclerotinia fungus, how it spreads, grows and causes crop losses.

Sclerotinia stem rot checklist

The sclerotinia checklist is intended to provide growers with background information to help them decide whether spraying their canola crop with a fungicide to control sclerotinia stem rot is economically justified.

The best control from a fungicidal application occurs before the majority of petals begin to drop-off and the pods set. The fungicide provides protection to the plant for at least nine days when applied at 20 to 30 per cent bloom stage. Because of the short time of four to eight days from first flower to 20 - 30 per cent bloom, a custom applicator should be booked as early as possible unless you apply the fungicide yourself.

The objective of the fungicide application is to cover as many petals as possible. Put another way, the crop should be sprayed at its "yellowest", on the day(s) when the maximum number of flowers are open.

When petal fall takes place it allows the maximum number of fungicide-covered petals to fall into the canola canopy (lower leaf axils, leaves and shoots), taking the fungicide along. Infection of the canola plant will only take place from sclerotinia infected petals. When the petals fall into lower leaf axils the presence of one or more petals carrying fungicide will likely prevent sclerotinia infection.

Fungicide application rates for both ground and aerial application are in the text *Crop Protection With Chemicals*, Alberta Agriculture, Agdex 606-1.

When to complete the checklist - Fill out the checklist and assess the crop shortly after first flower. First flower occurs when 75 per cent of the canola plants have three open flowers on the main stem. This usually occurs during the last week of June or the first week of July.

How to complete the checklist - Read one question and circle the point value assigned to the answer you would choose for each section. Count the points and enter the total for each section. Answer all the questions.

Section one

1. Have you previously had a good crop at flowering and poor yields at harvest, even though growing conditions were favorable?

Yes _____ 20

No _____ 0

2. Have you seen sclerotinia rot in your crop in previous years?

Yes _____ 20

No _____ 10

3. Have you heard of stem rot problems in your area in the past 2 to 3 years?

Yes _____ 10

No _____ 5

4. Have you seen black sclerotes in your harvested seed in the past 2 to 3 years?

Yes _____ 20

No _____ 10

5. In previous years have your canola crops lodged?

Heavily _____ 20

Moderately _____ 10

Lightly _____ 0

6. Do you see large swaths at harvest but get low yields?

Yes _____ 10

No _____ 0

7. If you sprayed a stem rot fungicide in previous years, what were the results?

Better crop _____ 20

No difference _____ 0

Total points for section one _____

If you scored 60 or more in this section, you probably had sclerotinia stem rot in your canola crops. Proceed to section two with a 60 or more score.

Section two

8. When you walk through the crop during the morning at the beginning of flowering, are your boots and pant legs wet when you come out?

Yes _____ 20
No _____ 10

9. Have you had wet weather in the immediate area within 2 to 3 weeks prior to flowering that allowed the soil to remain moist for extended periods?

Yes _____ 20
No _____ 10

10. Were apothecia found in the field, around the field, or in any neighboring cereal or canola fields where canola was growing in the previous 1 to 3 years?

Yes _____ 20
No _____ 10

11. Do you believe the weather will remain dry throughout the flowering stage of the crop?

Highly likely _____ 0
Moderately likely _____ 10
Not likely _____ 20

Total points for section two _____

If you had a high score in section one and more than 50 for section two, you should consider applying a fungicide to protect your crop against sclerotinia stem rot.

Section three

12. What is the condition of your stand in terms of height, vigor and uniformity?

Excellent _____ 20
Good _____ 10
Fair _____ 5
Poor _____ 0

13. When you walk through your crop, how dense is the canopy?

Light _____ 0
Moderate _____ 10
Very dense _____ 20

14. What is the yield potential of the stand?

10-20 bu/ac _____ 0
20-30 bu/ac _____ 10
Greater than 30 bu/ac _____ 20

15. In previous years, when your yield potential was 30+ bu/ac, what were the actual yields?

Greater than 30 bu/ac _____ 0
20-30 bu/ac _____ 20

Total points for section three _____

If you have scored 50 or higher in section three, along with high scores from the first and second sections (60 and 50 plus respectively), it may be worthwhile to protect your crop against sclerotinia stem rot. If you scored less than 50 in the last section it is not likely worth applying a foliar fungicide.

Growers can apply fungicide for sclerotinia control and achieve good to excellent results in the standing crop. Unfortunately, this disease may progress rapidly in the swath in wet years particularly in Argentine cultivars. Do not swath canola if rain is forecast, particularly if the crop is immature (green) when cut. Sclerotinia rot progresses rapidly in wet dense, compacted swaths, particularly on the turns.

The disease can be detected by a "rotten egg" smell coming from the swaths. This problem is obviously more prevalent in the wetter regions of the province. The heavier and more compact the swath, the greater the likelihood for sclerotinia to rot the swath before combining.

Management Strategy - Canola

Follow a crop rotation that allows at least three to four years between susceptible crops. Sclerotes can remain viable for three or more years. Cereals, corn and grasses are immune. Mustard, field peas, beans, carrots, potatoes, lentils, soybeans, safflower, flax, clover and many weeds are susceptible to some degree to infection by this fungus.

- Use clean seed, free of sclerotes.
- Control susceptible weeds and volunteers in cereal crops.
- Swath early. This may reduce losses caused by shattering in canola.
- Do not exceed normal seeding rates and seed uniformly. Dense stem growth promotes disease development.
- High fertilizer inputs promote leafy crop canopies that favor disease development.

Up to one-third of the canola crop may be lost in the swath from sclerotinia rot. This reduces the quality of the grain and increases the number of sclerotes.

- Direct combine.
- Do not swath immature stands (at least 30 per cent of the seed must be ripe).
- Do not swath if rain is in the immediate forecast.
- Avoid compacting swaths.
- Use a high cut to allow for better drying.

SEEDLING BLIGHT, DAMPING-OFF, ROOT ROT

Rhizoctonia solani, *Pythium* spp., *Fusarium* spp.

Biology

Damping-off is a collective term used to describe seed decays and seedling blights. There can be pre-emergence seed decay when the seedling never emerges or post-emergence seedling blight or damping-off when seedlings die soon after emergence. Because seed coats may be cracked during harvest, seedling blight is often a problem in flax, canola, rape and mustard. Canola seedlings, as well as rape and mustard seedlings, may be severely affected by seedling blights if planted into cold dry soils unusually early in the season.

Fungi can attack damaged or healthy seeds as soon as they absorb water before germination. Infected seeds may die before they emerge (pre-emergence). Plants that are affected by disease after germination may die or grow with less vigor and yield less than healthy plants.

Conditions required for seedling blight depend on the pathogen present. Cold damp soils favor *Fusarium* species while loose, cold, dry well-worked soils favor *Rhizoctonia solani*, and wet heavy soils favor *Pythium* species. *Rhizoctonia solani* is the causal fungus in most disease problems of seedling canola and flax.

Damage Description

Patchy emergence is usually the first symptom of seedling blight. Affected seeds may fail to germinate and rot or they may germinate but fail to reach the surface because of fungal disease. After germination and emergence, seedlings may appear to stagnate and "disappear" under dry windy conditions. Examination of these seedlings will show a girdling of the seedling stem at or just below the soil surface.

Mature plants may also be attacked by these fungal pathogens. The resulting disease may be root rot caused by *Rhizoctonia solani* or foot rot by *Fusarium* species or occasionally a damping-off caused by *Pythium* species. Infected areas on the lower stems, typical of *Fusarium* infection may be sunken and black bordered, containing pink-colored spores during wet conditions.

Direct yield losses occur as a result of loss of plants at the seedling stage. Surviving diseased plants may produce less seed or die before the seed is ripe. Flea beetle infestations coupled with seedling blight disease can result in a major loss of stand and consequent yield loss. On severely infested land, seedling blight may result in a 100 per cent loss of stand.

If seedling losses are uniform throughout the stand, surviving canola plants will compensate by growing larger. If the loss is patchy and large areas die out, then compensation cannot take place and yield losses result. Weed infestations also take over on these bare patches of soil.

Diagnosis

Unless soil conditions are unusually dry, uniform seedling emergence should have taken place around seven days after planting. Check the stand every few days for seedling blight and possible flea beetle damage.

Management Strategy

- Seed shallowly (2 cm) into warm moist soil when possible.
- Sow seed with a high germination rate into a firm seedbed and pack the soil to bring the moisture around the seed.
- Maintain soil fertility. Inadequate or unbalanced nutrition favors seedling blight. Fertilizer placed with seed may reduce or delay emergence, no more than 9 lb N or 18 lb P₂O₅/ha should be placed with the seed.
- Minimum soil temperatures at the 5 cm level for seedling should be 3-5°C for Argentine or 5-8°C for Polish types.
- Use a crop rotation. Avoid canola after canola. Flax should follow another crop rather than summer fallow. Avoid legumes and sugar beets in flax rotations as they are susceptible to the same *Rhizoctonia* strains.
- Control volunteer flax, canola and cruciferous weeds.
- Adjust your combine. Proper combine adjustment helps prevent cracking of seed coats, which favors increased seedling disease problems.
- If seedling blight damage is extensive and patchy, consider reseeding if the soil has warmed and remains moist or rotate to a cereal crop.
- Use one of several recommended fungicides and fungicide-insecticide combinations for effective control of seedling diseases and insect pests.

STAGHEAD, WHITE RUST

Albugo candida

Biology

Staghead or white rust only affects Polish canola (*Brassica rapa*); Argentine types (*B. napus*) are immune. With the introduction of the Polish variety Tobin, which has good resistance to this disease, levels of staghead fell in the early eighties. Tobin then occupied almost 100 per cent of the Polish canola acreage. The gene controlling staghead resistance occurs in 40 per cent of Tobin plants. In most years, this level of resistance seems to hold-up. In recent years cultivars such as Colt, Eldorado and Horizon, which are susceptible to staghead, have allowed levels of this disease to build-up again. Parkland, Goldrush and Reward along with Tobin are the recommended resistant types.

This fungus overwinters as thick-walled spores in the characteristic stagheads in the crop residue or as pieces of stagheads contaminating seedlots. In spring, these spores germinate and infect canola seedlings. Infection results in white pustules on the underside of leaves, the white rust stage. These pustules release spores that can infect other leaves, stems and flowers. Stagheads result when the flower spikes are infected.

Damage Description

Pustules on the underside of the leaves are white to cream colored. These may be present from the seedling stage to maturity. Raised green pustules that turn white during wet periods may also form on leaves, stems and flower heads. Infected heads, which give this disease its name, stand out

sharply in the crop. As the stagheads mature, they turn from green to white to brown and become hard and brittle.

Before the introduction of Tobin, losses of up to 20 per cent were recorded from this disease. Now losses from staghead and white rust while typically much less than an estimated 20 per cent are none-the-less obvious in susceptible cultivars.

Staghead infection may destroy from 5 to 90 per cent of the seed-producing potential of individual plants.

Yield losses can be related directly to the percentage of staghead-infected spikes among the normal spikes, although staghead infested plants are said to pod shatter much more readily than non-infected plants.

The white rust of shepherd's purse, (*Capsella bursa pastoris*), which is a common disease in Alberta does not infect canola species.

Management Strategy

- Use resistant varieties to reduce spore levels. See appendix.
- Follow a crop rotation.
- Control volunteer canola and closely related cruciferous weeds.
- Use clean seed. Seed can become contaminated when stagheads break up during harvesting and form seed-sized pieces.

STEM BREAK AND BROWNING

Polyspora lini

Biology

Browning and stem break of flax are two phases of this disease.

The fungus overwinters on the seed or infected crop residue. As the seed germinates and the seed coat is lifted above the soil by the cotyledon leaves, spores on the seed coat infect the new leaves. Wind and splashing rain spread the spores within the crop.

The disease is favored by warm humid conditions.

Damage Description

The browning phase generally appears late in the season. Plants develop grey-brown areas with purplish margins on leaves, stems and bolls. Affected plants usually appear in patches giving the crop a mottled look. Stem breaking, which occurs throughout the season, results from enlarging stem cankers caused by early infection.

Seedlings may be killed if infected early. In some years this fungus is responsible for appreciable damage in the

parkland regions of Alberta and Saskatchewan.

Yield loss is directly proportional to the percentage of broken stems.

Diagnosis

Check random areas of the field for this disease because it may affect the flax crop in widely scattered patches.

Management Strategy

- Use a three-year crop rotation. This reduces infection derived from disease-infected residue.
- Use disease-free seed from flax crops produced in drier growing regions of the prairies.
- Seed as early as possible. This may result in a vigorous crop better able to withstand disease infection later in the season.
- Treat seed with a recommended fungicide.

VERTICILLIUM WILT, LEAF MOTTLE

Verticillium dahliae

Biology

Verticillium wilt is a destructive disease of sunflowers. It also affects many broad-leaved weeds, which may not show any disease symptoms.

This fungus overwinters in the soil and crop residue as tiny black resting bodies or sclerotes. These germinate and invade the root tips to produce more spores inside the plant tissue. Spores then move through the water conducting vessels to the above-ground parts of the plant. Spores infect the head and seed and become seed-borne.

This disease is favored by high moisture and cool temperatures.

Damage Description

Symptoms first develop on lower leaves and gradually move to higher leaves. Leaves become pale green, yellow, then brown, giving the mottled appearance. Black streaks may occur at the stem base. A cross section of the lower stem reveals a brown coloration of the water conducting tissue. Premature death may result. Diseased heads are small. Masses of tiny sclerotia are produced in infected plants. The fungus can survive for at least 12 years in infested soil.

Both seed yield and quality are reduced by this disease, but fortunately most sunflower cultivars are resistant to this fungus.

Management Strategy

- Use resistant cultivars.

Resistant cultivars: Cadet, Capri, Cargill 205, Cargill 207, SF 103, Challenger, Dakota Gold II, DO 164, IS 7000, IS 7101, IS 7111, MRS 40, ST 330, Sigco 422, Sigco 452, Sigco 465 A, Sigco 954, Sigco 974, Sunwheat 101, XF 6240, XF 6440.

Intermediate cultivars: D 131, DO 707, DO 855, Hybrid 894, K 837, Royal Hybrid 2141, S 1296, Sigco 964, Trison 849.

Susceptible cultivars: Commander

- Follow a crop rotation. Sunflowers should not be grown more than once every five years even if the disease is assumed to be absent. The wilt fungus will persist for at least 12 years in infested soil, but rotations prevent a rapid build-up of the fungus in the soil.
- Control volunteers and broad-leaved weeds.
- Use disease-free seed to avoid introducing the fungus to disease free areas.

DISEASES OF FORAGE LEGUMES

BACTERIAL WILT

Corynebacterium michiganense pv. *insidiosum*

Biology

Bacterial wilt causes losses in all alfalfa growing areas, but it is most damaging in the irrigated areas of Western Canada.

Bacteria overwinter in the roots and residue of diseased plants. They are transported by soil and irrigation water to infect healthy plants through wounds in the roots and crown or through the cut ends of newly swathed stems. Wounds can result from winter injury, nematode feeding or mechanical injury. The bacteria multiply and block the water conducting tissues and eventually cause severe damage or death.

This disease is favored by high humidity and is most severe on low lying, poorly drained land.

Damage Description

Diseased plants are usually scattered throughout a stand. Plants are stunted and light green. Stunting is more apparent during re-growth after alfalfa is cut. Stems are shorter and leaves are smaller and curled at the edges. During warm dry spells, plants may wilt first at the tips, then the whole plant; death may follow. Winterkill is a problem with disease-weakened plants. A cross section of the tap root shows a brownish discoloration around the woody centre.

This disease lowers quality and quantity of hay and seed and reduces the life span of the stand.

A 10 per cent infection can cause yield losses of 5-6 per cent owing to some compensation from adjacent healthy plants.

Diagnosis

Regrowth after the second cut will show the severity of the infection.

Management Strategy

- Use resistant varieties.
- Stem nematodes may transmit bacteria. Use Trek, which is nematode and bacterial wilt resistant, in the irrigated areas where both problems occur. Trek, Barrier, Trumpetor and Ambassador are resistant to both bacterial and Verticillium wilt.
- Follow a crop rotation with no more than four consecutive years of alfalfa.
- Harvest young stands before old ones when using the same equipment.
- Thoroughly clean and disinfect mowers after infested field are cut.
- Do not cut alfalfa that is wet.
- Do not over irrigate. Overflow water transports bacteria.

BLACK STEM

Alfalfa - *Phoma medicaginis* var. *medicaginis* (syn. *Ascochyta imperfecta*), **Clover** - *P. trifolii*, **Sweet-clover** - *P. meliloti*

Biology

This disease occurs in all alfalfa and clover growing areas of Canada. However, it is most destructive in warmer regions.

Black stem overwinters on the seed, crop residue and in cankers on alfalfa and clover. Spores are produced in spring and are spread by water, wind and insects. New shoots are infected as they grow through the crop residue. During the summer, black stem infections decrease or slow, but may build up again in autumn. The fungus can survive on plant stems and seeds for approximately two years.

This disease is favored by cool moist weather.

Damage Description

Black stem may infect all above-ground parts of the plant,

including the crown and upper roots. In spring, small irregular dark brown to black spots develop on the lower stems and leaves. As these spots enlarge and join together, stems turn black and upper leaves, flowers and pods may drop.

Death of leaves and stems decrease quality and quantity of hay. Flower and pod drop causes seed yield losses.

Diagnosis

Look for this disease during late spring or early summer.

Management Strategy

- Use resistant varieties. See appendix.
- Follow a rotation with crops that are not legumes.

- Spring burning is sometimes recommended but may harm plants if new growth has already started.
- Use certified seed from a dry area, which is less likely to contain infested seed.
- Cut early when the disease is prevalent to reduce leaf loss in the hay crop.

COMMON LEAF SPOT, PSEUDOPEZIZA LEAF SPOT

Pseudopeziza trifolii

Biology

Common leaf spot is a destructive disease of alfalfa and to a lesser extent of sweet-clover.

The fungus overwinters on infected plants and crop residue. Spores produced in the spring are forcibly discharged into the air and carried by the wind to growing plants.

The disease is favored by dense crop stands and cool, wet weather, particularly in early July.

Damage Description

Sharp brown circular spots develop on the leaflets. Older spots have a paler raised disc in the centre. Infected leaves turn yellow and drop before swathing.

Premature defoliation reduces plant vigor (winter hardiness), hay quality and yield.

Diagnosis

Look for this disease in late June.

Management Strategy

- Harvest early. This reduces leaf loss and build-up of disease levels on the crop foliage.
- Harvest the crop completely to reduce the level of diseased plant residue.
- Control volunteer legumes in headlands. These legumes serve as reservoirs for this disease.

CROWN ROT, ROOT ROT

Fusarium spp., *Pythium* spp., *Phoma* spp., *Rhizoctonia* spp., *Phytophthora magasperma*

Biology

Crown and root rot are the most common diseases of alfalfa and clover. Occasionally, the disease is caused by just one fungus such as *Phytophthora* root rot but more often it is caused by a complex of organisms. This complex may include several genera, species or strains of fungi that interact with non-pathogenic organisms and various environmental factors to cause rot.

Each species may have some variation to this life cycle, but generally they overwinter in the soil or on plant residue. They enter the roots or crown directly or through wounds. The rot develops slowly in the taproot and crown but rapidly on smaller roots.

Every fungus species has a set of conditions that favor its growth. *Fusarium* growth is enhanced by frost, poor drainage, low fertility, frequent harvests and foliar diseases. Crown bud rot caused by *R. solani*, *Fusarium* species, and *Phoma medicaginis*, is common after the second year of growth on irrigated or moist soils. *Phytophthora* root rot is most severe in cold, wet, poorly drained soil. Foliar diseases, foliar and root insects, frequent or untimely cuttings, early frosts, poor fertility, severe winter conditions, low light intensity, and low soil pH are examples of stresses that encourage root rot.

Damage Description

Fusarium crown and root rot produces rusty-brown to dark brown streaks in the water conducting tissue of the root and crown. Large sections of the crown can be destroyed, leaving only a few side shoots alive.

Crown bud rot produces dark brown to black patches that occur on the bud tissue and move to the crown and upper root area.

Phytophthora root rot produces yellow brown patches on the tap root that may extend to the crown. Plants of all ages are susceptible but seedlings are particularly prone. Plants turn yellow, wilt and die.

Brown root rot (*Phoma sclerotoides*) produces circular light to dark brown areas spread throughout the roots and up to the soil surface. Black dots (pycnidia or spore-producing structures) are present on the diseased areas. In the spring, stunted yellow plants often die after initial growth. Brown root rot affects alfalfa, red clover, alsike clover, sweet-clover and bird's-foot trefoil. It also has been associated with a root rot of winter wheat and fall rye.

Crown and root rots affect the yield and life span of the stand. Loss of crown buds and stems lowers yield; thin stands allow weeds to invade and poorer hay or seed quality is the consequence.

Diagnosis

Look for this disease during late spring to early summer before flowers are produced.

Management Strategy

Reduce the population of the disease organisms and avoid plant injury.

- Use cereals in a crop rotation for two to three years to reduce the fungus population.
- Maintain a proper cutting schedule. Late summer and early fall harvests do not give plants sufficient time to store nutrients necessary for winter survival. Cut the late crop immediately after a killing frost.
- Maintain adequate soil fertility, especially phosphorus and potash, which are necessary to promote plant vigor.
- Avoid mechanical injury such as recurrent traffic over fields, which damages crown tissue.
- Grow the crop on well-drained soils.
- Maintain surface residue to trap and provide adequate snow cover. Deep snow helps to prevent winter cold

DOWNY MILDEW

Peronospora trifoliorum

Biology

This disease affects alfalfa, clovers and trefoil. Sweet-clover is seldom attacked.

This fungus overwinters in the crown buds and in crop residue. Following infection, downy mildew grows internally throughout the plant. Downy mildew is favored by wet or humid weather. Spores produced by the fungus are spread by wind and rain. The youngest leaves are most susceptible to infection.

Damage Description

Chlorotic areas appear on the upper leaf surfaces with a grey layer of fungus on the undersides. Infected plants are stunted and leaves twist and pucker.

This disease lowers the quality of the hay and reduces yield, particularly in the first cut.

Management Strategy

- Use resistant cultivars.
- Use crop rotation. This reduces disease build-up.
- Harvest cleanly to prevent re-infection from crop residue.
- Cut early. This may reduce leaf loss but will sacrifice yield.
- Burn stubble before spring growth begins. This can help in some instances.

GREY LEAF SPOT, STAGNOSPORA LEAF SPOT AND ROOT ROT COMPLEX

Leptosphaeria pratensis (asexual *Stagnospora recederis*)

Biology

This disease affects alfalfa and sweet-clover. In some areas, it is the most serious disease of sweet-clover. *L. pratensis* can also cause stem spots and crown and root rots.

The fungus overwinters in the diseased crop residue and crowns of overwintering plants, and is spread by spores produced on infected leaves.

Prolonged periods of wet weather in June and July favor disease build-up.

oles. Small black dots (pycnidia) form in the centre of the diseased spots. The fungus may attack the upper root and crown area and produce a dark red-brown dry rot.

Diagnosis

Losses are caused by leaf rot and loss of root functions. Hay yield and quality are reduced as well as plant vigor (winter hardiness). In most areas, *Stagnospora* leaf spot root rot complex is a minor disease, but it can cause injuries that enable other disease organisms to become established.

Management Strategy

- Harvest early. This reduces leaf damage and inoculum build-up.

Damage Description

Leaf spots are large, oval areas with light centres and dark margins. Dead leaves tend to remain attached to stems. Light-colored infected areas appear on the stems and peti-

- Burn the stubble before spring re-growth. This may help reduce inoculum levels.
- Follow a rotation with crops that are not legumes. This lowers disease potential.

LEAF PROLIFERATION

Biology

These diseases, clover phyllody mycoplasma-like organism (MLO) and clover proliferation (MLO), occur on alsike, red, white and sweet-clovers and bird's-foot trefoil. They are transmitted by leafhoppers (*Aphrodes bicinctus* and *Macrosteles fascifrons*).

These diseases are spread only by leafhoppers. Once these hoppers become infective they remain so until their death. MLOs overwinter in infected biennial and perennial plants.

Spread is dependent on the number of infective leafhoppers present.

Damage Description

No seed is produced by infected heads. Infected plants do not usually survive the winter, so the stand dies out.

Phyllody

Flower parts revert to leaf-like structures. Petals are

reduced and green, and the ovaries are replaced by leaves. Plants are stunted and a light-yellow color.

Proliferation

Profuse foliar growth appears from the crown and gives a witches' broom appearance. Flowers are green and modified in shape. Each flower becomes a cluster of green leaf-like appendages.

The percentage of witches' broom present during the growing season indicates the amount of die-off to be expected overwinter.

Management Strategy

No practical control is known. When stands become unproductive, cultivate and replace with a non-legume crop in the rotation.

POWDERY MILDEW

Erysiphe polygoni, *E. trifolii*

Biology

Powdery mildew is common on red clover in North America, but distinct strains of this fungus also affect alsike clover, sainfoin, alfalfa, trefoil and vetches.

These fungi overwinter as small pinpoint black dots (resting structures) on diseased plant parts. During the spring, these resting structures produce spores that infect the leaves. Wind is responsible for secondary spread of spores produced on diseased plant parts during the growing season.

Unlike most fungi, moderately dry weather favors development of this disease because wind-blown spores do not need free water to infect the host.

Damage Description

A light dry powdery layer of the fungus is visible on upper

surfaces of leaves, petioles and stems. Leaves turn prematurely yellow, then brown. Heavily diseased plants are usually stunted and unproductive.

Diagnosis

Severe disease outbreaks lower the hay quality and reduce yields.

Management Strategy

- Harvest early. This may slow the spread but sacrifices the hay yield.

SOOTY BLOTCH, BLACK BLOTCH

Cymadothea trifolii

Biology

Sooty blotch is common on alsike and white clovers and is sometimes found on red clover.

This fungus overwinters on diseased plants. Spores are spread by wind, water and insects.

This disease is favored by prolonged cool, moist conditions and is most prevalent in low wet areas.

Damage Description

Dark-green blotches appear on the leaves, which later turn black and sooty. Leaves wither when spots become numerous.

Diagnosis

Yield losses of hay and seed are caused by destruction of

foliage and failure to flower. Severely infected foliage may be toxic to livestock and cause ulcers of the mouth. Sooty blotch also affects the estrogen content of the leaves, which may lead to reproductive disorders in animals fed infected material.

Management Strategy

- Use a crop rotation with non-legumes for three years before re-seeding to clover.
- Harvest the crop cleanly. Cut the crop down to the crown area and completely remove the crop.
- Burn stubble in some instances.

TARGET SPOT, STEMPHYLIUM LEAF SPOT

Stemphylium botryosum, S. sarcinaeforme

Biology

Target spot is common all over the Prairie Provinces and survives for years in plant residue or soil. This disease may cause significant losses in late summer in dense stands during wet weather.

Damage Description

Leaf spots are oval, slightly sunken, dark brown with light centres and are usually surrounded by a pale-yellow halo. Older spots often show distinct concentric rings hence the name target spot.

Diagnosis

Target spot can cause losses of up to 50 per cent of the protein value of the crop by inducing heavy leaf drop.

Management Strategy

- Harvest early. This reduces losses in both quantity and quality of hay.
- Use a crop rotation with non-legumes.

VERTICILLIUM WILT

Verticillium albo-atrum

Biology

Verticillium wilt has long been a serious disease of alfalfa in Europe but its establishment in the United States and Canada only occurred in the late 1970s.

This fungus overwinters on infected plants, crop residue, seeds and possibly on host weeds. The fungus enters the root system and grows in the water-conducting tissue of alfalfa. Spores are transported by wind, direct contact between plants, running water (irrigation), footwear, harvesting equipment, alfalfa hay, alfalfa seed, residue and insects. This disease is favored by high moisture and temperatures below 18°C.

Damage Description

Symptoms are most striking on the second growth after harvest. There is a yellow blotchiness on young leaves near the top of one or more stems on a plant. Closer inspection reveals V-shaped yellow or brown areas at the tip of the leaflets, centering the mid-veins. These areas become pale and dry. Temporary wilting of upper leaves occurs on warm days. Although the leaves may be near death, the stem remains green and upright. Infected plants are stunted in older, more severe infections. Under high humidity, the fungus may grow and produce spores on the outside of dead stems.

Verticillium wilt can reduce yields by 50 per cent or more by the end of the third crop year. Productive lives of infected stands are reduced to three or four years from five or more. The nutrient quality of hay produced does not seem to be affected.

The presence of Verticillium wilt in a region endangers important export opportunities for dehydrated alfalfa, pedigree seed and leafcutter bees. Leafcutter bees may use infected alfalfa leaves to build their cocoons. Cocoons with immature bees are sold to other countries. Thus, the presence of verticillium wilt in a country may lead to restrictions on the export of leafcutter bees.

Diagnosis

There are no tolerance levels for this disease. One plant or seed sample with this disease means the restrictions on movement and treatment apply.

Field inspections should be handled by the producer as follows: walk each field randomly, when there is approximately 25-30 cm of plant growth, and just before flower production. Have plants that show symptoms of the disease tested at a diagnostic centre.

Management Strategy

Prevent introduction of the disease onto clean land. If the disease is present, eradicate it or grow resistant varieties.

- Use resistant varieties.
- Use clean, disease free, pedigreed seed to start new alfalfa fields. Plant on weed-free land that has not grown alfalfa for the past three years. Shepherd's-purse, redroot pigweed, lamb's-quarters and dandelions are susceptible to this disease.
- Badly infested fields should be plowed under.
- Keep stands vigorous by following proper irrigation, weed control and fertilization practices.
- Treat alfalfa seed with *Rhizobium* inoculant. The inoculant encourages proper nodulation and vigorous growth through its ability to fix nitrogen.
- Clean plant debris from harvesting equipment and disinfect with steam or a 2 per cent formaldehyde solution.
- Do not graze livestock on infected fields. *Verticillium* fungus can be spread in the manure. Do not spread contaminated manure onto forage fields.
- The *verticillium* fungus remains viable after dehydration.
- Irrigate disease-free fields first.
- Control insect vectors.

VIRAL DISEASES

Biology

There are many types of virus and virus-like diseases that affect forage legumes. The symptoms of each disease may differ, but they will be dealt with as a group because disease cycles and control measures are similar.

Viruses can be transmitted by insect vectors, mechanical damage, plant to plant contact, pollen and seed. Alfalfa mosaic virus (AMV) is transmitted primarily through the seed; from 2 to 31 per cent of the seed produced by an infected plant is also infected. In addition, this virus can be transmitted by aphids, especially the pea aphid (*Acyrtosiphon pisum* and the green peach aphid (*Myzus persicae*). Other viruses transmitted by aphids are bean yellow mosaic virus (BYMV), pea streak virus (PSV) and red clover vein mosaic virus (RCVMV). Lucerne transient streak virus (LTSV) is spread only by mechanical transmission. No vectors or seed transmission have been observed.

Viruses that are transmitted mechanically and by insect vectors overwinter in infected wild and cultivated legumes. Perennial legumes such as vetch and medic serve as reservoirs for AMV.

The vast majority of the insect vector species do not survive the winter and must be blown in annually from the United States. Some of these migratory insect species may already be carrying viruses or MLOs that will infect forage legumes.

Damage Description

Viral diseases produce many types of symptoms. The most common symptom is stunted or dwarfed plants or foliar symptoms such as mosaics. These discolorations may be mottling (AMV or BYMV), streaking (LTSV), or vein clearing (CYMV). Some virus diseases are symptomless in their hosts.

Diagnosis

All viral diseases cause a reduction of total yield as well as reduced life span of the stand. AMV can cause up to 30 per cent loss in forage yield and up to 54 per cent reduction in dry matter content. LTSV has caused up to 18 per cent reduction of dry matter in alfalfa. Viral infections can also reduce root nodulation and winter survival of plants.

Management Strategy

Little can be done economically to control these diseases. Generally, they take from two to many years to build-up. Along with fungal and bacterial diseases they are responsible for the gradual loss of productivity of legume crops. Stands that are not productive after a number of years should be plowed under and replaced with non-legumes in the rotation.

WINTER CROWN ROOT ROT, SNOW MOLD

Coprinus psychromorbidus (LTB phase), *Fusarium nivale*, *Typhula ishikariensis*

Biology

These fungi infect all legumes and forage grasses. They are extremely widespread and can be especially damaging in the central and northern areas of Alberta and Saskatchewan where prolonged snow cover occurs. Prolonged snow cover favors disease development.

The fungi survive in the soil until conditions are favorable for them to grow and infect the plant crowns. *Coprinus psychromorbidus* is active at temperatures near freezing, while *Fusarium nivale* can become active as soon as plants are dormant.

Damage Description

Dead plants in the field are the first indication of this disease. A dark brown rot appears on the crown tissue and affected plants may be killed. Reduced yield results from patchy stands.

Diagnosis

Look for this disease during late spring.

Management Strategy

Maintain a vigorous stand with a variety or mixture recommended for the region.

YELLOW LEAF BLOTCH

Leptotrochila medicaginis

Biology

Yellow leaf blotch is a major leaf disease of alfalfa and is common in central and northern prairie regions. The fungus overwinters on crop residue. Spores are released during the spring and infect new growth. The resulting blotches do not produce spores until the following spring.

Disease incidence is highest when periods of wet and hot dry weather alternate.

Damage Description

Symptoms are most prevalent in late spring and early summer. Elongated, yellowish blotches appear parallel to leaf veins on the leaves, stems and petioles. Black dots (pycnidia) appear on the diseased leaf surface and infested leaves curl downward before they dry up and fall.

Diagnosis

Premature defoliation reduces vigor, hay quality and yield.

Management Strategy

- Use resistant cultivars.
- Cut early to reduce losses and reduce build-up of infected leaves.
- Use a crop rotation with cereals.

DISEASES OF PULSE CROPS

There has been a steady increase in the acreage of pulse crops (edible grain legumes) in recent years. This is the result of new markets for human and animal consumption, newly adapted varieties for prairie conditions, and their acceptance as new crops to add to a rotation.

The lack of disease resistance in many pulse crops calls for the use of cultural methods as the primary way to control diseases.

Plant clean certified disease-free seed on un-infested land to ensure that no new diseases are introduced. Seed-borne diseases such as ascochyta blight of fababeans and peas and anthracnose of beans are controlled this way.

Use rotations with cereal crops. This will allow the pulse crop residue to break down and reduce the levels of short-term, soil-borne diseases such as root rots, seedling blights, sclerotinia and chocolate spot of fababeans. Broad-leaved crop volunteers and weeds must be controlled in combination with rotations to destroy all hosts upon which the diseases may survive.

Use proper sanitation including the removal of diseased plants. Plow under infected crop residue to control diseases such as powdery mildew on fababeans, anthracnose or common blight on field beans. Till to reduce disease by burying crop infested residue to allow faster decomposition and destruction of the material by soil micro-organisms. Tillage reduces movement of fungal spores by wind and allows greater root penetration, which helps beans to form a deep root system to escape fusarium root rot infection.

Use good growing practices to promote vigorous healthy seedlings. Tillage will control diseases and weeds as well as prepare a proper seedbed. Plant seeds as shallow as possible to conserve seedling energy for growth to the surface, and to give less time for the seed and seedling diseases to infect. Avoid close plant spacing and over-fertilization with nitrogen; both promote dense heavy canopies

that provide the moist humid environment that encourages leaf diseases and sclerotinia white mold. Test soil to determine the amount of fertilizer needed. Plant seed on well-drained land to minimize soil-borne diseases. Excessive irrigation will increase most foliar diseases, while powdery mildew may be reduced by the application of water. Do not cultivate or enter fields during wet weather or while dew is still on the foliage. This will help reduce the spread of anthracnose and bacterial diseases that require water on the leaf for infection. To reduce infestation by wind-blown spores, do not plant new fields near old stubble. This practice is recommended for mycosphaerella blight and powdery mildew of peas. Use proper care in harvesting the dry seed of pulse crops. Adjust combines properly to avoid damaging seed coats and to remove crop residue in the seed that may carry disease.

Pulse crops are members of the legume family, which includes forage crops such as alfalfa, clovers and sainfoin. Legumes are able to form a mutually beneficial relationship with certain strains of soil bacteria called *Rhizobium*. *Rhizobia* invade the roots of legumes, where they cause swelling or nodulations. They are able to take gaseous nitrogen from the soil and convert it to a form that is available to the plants. Legumes in return supply sugars and carbohydrates to the bacteria. *Rhizobia* are capable of fixing 60-200 lb/ac of nitrogen; therefore little to no nitrogen fertilizer may be needed.

Strains of *Rhizobium* bacteria occur naturally in soils but in many instances the most effective strain for given legume species may be absent.

Legume seeds should be inoculated with the appropriate strain of *Rhizobium* to ensure early and proper nodulation. Plants that are inoculated are healthier and able to cope better with diseases.

Use resistant varieties when possible. Resistance is the most economical and efficient means of disease control.

APPENDIXES

Barley cultivar resistance to specific diseases

	Barley yellow dwarf	Common root rot	Covered/ False loose smut	Ergot	Leaf stripe	Loose smut	Net blotch	Scald	Speckled leaf blotch	Stem rust
*Abee"F	S	I	I	I	R	S	S	S	S	S
AC Stacey"F	-	-	R	-	-	S	I	R	-	S
Argyle"M	S	I	S	I	I	S	S	S	S	R
B1215	-	-	I	-	-	S	-	-	-	-
Bedford	S	I	I	-	I	S	S	S	S	R
Bonanza"M	S	I	S	I	R	S	S	S	S	R
Brier"F	-	-	R	-	-	S	I	I	-	R
B1602"M	-	-	I	-	-	S	S	S	-	R
*Bridge"F	-	-	I	-	-	S	-	-	-	-
CDC Creme"M	-	-	I	-	-	S	-	-	-	-
CDC Buck"H	-	-	S	-	-	S	-	-	R	-
*CDC Richard"H	-	-	I	-	-	S	-	-	-	-
*Condor"H	S	I	S	-	-	S	S	S	S	R
Conquest	I	I	I	I	I	S	S	S	S	R
*Deuce"F	S	I	R	-	-	S	S	S	S	R
Diamond	S	S	R	I	R	S	I	I	I	R
Duel"M	-	-	I	-	-	S	-	-	-	-
Duke"SD	S	I	I	-	-	S	S	R	S	R
*Ellice	S	I	S	-	I	S	I	S	S	R
*Elrose	S	I	I	-	S	S	S	S	S	S
Empress	S	I	S	I	S	S	S	I	S	R
Galt"F	S	S	R	S	S	S	S	S	R	R
Gateway 63	S	S	I	-	I	S	S	S	S	S
*Harrington"M	S	I	S	I	S	S	S	S	S	S
Heartland"F	S	I	I	I	I	S	I	S	S	R
*Herta	S	I	S	-	I	S	S	S	S	S
Iona	-	-	I	-	-	S	-	-	-	-
Jackson"F	S	S	S	S	S	S	S	S	S	S
Johnston"F	S	S	S	I	S	S	S	I	S	R
*Klages"M	S	I	R	I	I	S	S	S	S	S
Klondike	S	I	I	S	S	S	S	S	S	R
Leduc"F	S	I	R	I	S	I	I	R	S	R
Melvin	S	S	I	S	S	S	S	S	S	R
Noble"F	S	S	I	-	-	S	S	S	S	R
*Norbert	I	I	I	S	I	S	I	S	S	R
*Manley"M	-	I	I	-	-	S	S	S	-	-
Olli	S	S	I	-	S	S	S	S	S	S
Otal"F	S	S	I	S	S	S	S	S	S	S
Samson"SD	S	I	I	I	-	S	S	S	S	R
*Stein"M	-	-	I	-	-	S	-	-	-	-
Tankard	-	-	S	-	-	S	-	-	-	-
Tupper	S	I	S	I	-	S	S	S	S	S
Virden"F	S	I	I	-	-	I	I	S	S	R
Winchester"SD	S	I	R	-	-	S	I	R	S	S
*Winthrop"M	-	S	R	-	-	S	S	S	-	-

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta,

*=Two-row barley, M=Eligible for malting, SD=Semi-dwarf, F=Feed type, H=Hulless.

Wheat cultivar resistance to specific diseases

	Barley yellow dwarf	Common bunt	Common root rot	Ergot	Leaf rust	Loose smut	Powdery mildew	Septoria complex	Stem rust	Stripe rust
Common										
Benito	S	I	I	I	R	R	-	-	R	R
Bluesky	S	I	R	-	R	R	-	I	R	R
CDC Makwa	-	I	-	-	-	R	-	-	-	-
Canuck	S	R	I	I	S	I	-	-	S	R
*Columbus	S	R	I	I	R	I	-	-	R	R
*Conway	S	I	I	-	I	R	-	-	R	R
Glenlea	S	I	R	S	I	R	-	-	R	R
*Katepwa	S	R	I	I	I	R	-	-	R	R
*Kenyon	S	I	I	-	R	I	-	-	R	R
*Lancer	S	R	I	-	R	R	-	-	R	R
*Laura	S	S	I	-	I	I	-	-	R	R
*Leader	S	R	S	I	S	I	-	-	S	R
*Neepawa	S	I	I	I	I	R	-	-	R	R
*Park	S	I	I	I	S	R	-	-	S	R
Pasqua	-	S	-	-	R	I	-	-	-	-
*Roblin	S	S	I	-	R	R	-	-	R	R
Selkirk	S	R	I	-	I	R	-	-	R	R
Sinton	I	I	I	I	R	S	-	-	R	R
Wildcat	S	S	I	-	R	R	-	-	R	R
Prairie spring										
*Biggar	-	S	I	-	I	S	-	-	-	-
*Cutler	-	S	I	-	-	S	-	-	-	-
*Genesis	-	S	I	-	-	I	-	-	-	-
*Oslo	S	I	I	-	R	S	-	-	R	-
Durum										
Arcola	S	R	I	-	R	I	-	-	R	S
Hercules	S	R	I	S	R	I	-	-	R	S
*Kyle	S	R	I	-	R	S	-	-	R	S
Macoun	S	R	I	I	R	I	-	-	R	S
*Medora	S	R	I	S	R	I	-	-	R	S
Pellisier	S	R	I	-	S	I	-	-	S	S
Plenty	-	-	-	-	-	S	-	-	-	-
*Sceptre	S	R	I	-	R	S	-	-	R	S
*Wakoona	S	R	I	I	R	I	-	-	R	S
Wascana	S	R	I	I	R	I	-	-	R	S
Soft white										
*Fielder	S	S	I	I	S	S	I	-	S	S
Owens	S	S	I	I	S	S	I	-	S	R
*SWS 52	-	S	S	-	-	S	-	-	-	R
Winter										
Harmil	-	-	-	-	-	I	-	-	-	-
*Norstar	S	S	S	I	S	S	-	-	S	S
*Norwin	S	S	S	-	S	S	-	-	I	S
Rebecca	-	-	-	-	-	R	-	-	-	-
Sundance	S	S	I	I	S	S	-	-	I	S

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta

Oats cultivar resistance to specific diseases

	Covered/Loose smut	BYD	Crown rust	Stem rust
*Athabasca	S	S	S	S
*Calibre	S	S	S	S
*Cascade	S	S	S	S
*Derby	I	S	S	S
Dumont	R	I	R	R
Fidler	R	S	R	R
*Foothill	S	S	S	S
Fraser	I	S	S	S
Garry	I	S	S	S
*Grizzly	S	S	S	S
*Harmon	I	S	S	S
*Jasper	S	S	S	S
Kelsey	I	S	S	S
Random	S	S	S	S
Riel	R	S	R	R
*Robert	R	I	R	R
Rodney	I	S	S	S
Terra	S	S	S	S
Vicar	S	S	S	S
Victory	S	S	S	S
*Waldern	I	-	S	S

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta

Rye cultivar resistance to specific diseases

	Stem smut
Antelope	I
Cougar	S
*Danko	-
Frontier	I
Gazelle (spring)*	-
*Kodiak	R
*Musketeer	R
*Prima	I
Puma	I
Rymin	R
Sangaste	R

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta

Triticale cultivar resistance to specific diseases

	Common bunt	Common root rot	Leaf rust	Stem rust
Carman	R	I	R	R
*Frank	R	I	R	R
*Wapiti	R	I	I	R
Welsh	R	S	S	R

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta

Canola cultivar resistance to specific diseases

	Altenaria black spot	Blackleg ¹	Sclerotinia stem rot	Common root rot	White rust/ Staghead
Argentine					
<i>Brassica napus</i>					
*AC Elect	-	3	-	-	-
*AC Excel	-	3	-	-	R
*AC Tristar	-	5	-	-	R
*Alto	-	5	-	-	R
*Bounty	-	4	-	-	R
*Celebra	-	3	-	-	R
*Crushen	-	3	-	-	-
*Cyclone	-	2	-	-	-
*Delta	-	3	-	-	R
*Garrison	-	2	-	-	-
*Global	S	2	S	S	R
*Hyola 401	-	4	-	-	R
*HC 120	-	4	-	-	R
*Legend	-	3	-	-	R
*Profit	-	3	-	-	R
*Stallion	-	3	-	-	R
*Vanguard	-	3	-	-	R
*Westar	S	5	S	S	R
Polish					
<i>Brassica campestris</i>					
<i>(B. rapa)</i>					
AC Parkland	-	4	-	-	R
Colt	-	4	-	-	S
Eldorado	-	4	-	-	S
Goldrush	-	4	-	-	R
Horizon	-	4	-	-	S
Reward	-	4	-	-	R
Tobin	VS	4	S	S	R

VS=Very susceptible, S=Susceptible, -=Reaction unknown, *=Recommended for Alberta

¹ In regions with high incidences of blackleg, when canola follows canola the disease ratings are as follows:

Rating	Rating	Percentage of stems infected
Highly susceptible	5	90-100
Susceptible	4	70- 89
Moderately susceptible	3	50-69
Moderately tolerant	2	30-49

Alfalfa cultivar resistance to specific diseases

	Bacterial wilt	Black stem	Common leaf spot	Downy mildew	Verticillium wilt	Winter crown rot	Yellow leaf blotch
Algonguin	R	-	-	R	-	-	-
Alouette	R	-	-	-	-	-	-
Ambassador	R	-	-	-	R	-	-
Anchor	R	-	-	-	-	-	-
Angus	R	-	-	R	-	-	I
Anik	S	-	-	R	-	R	R
Apica	R	-	-	-	-	-	-
Arrow	I	-	-	-	-	-	-
Award	R	-	-	-	S	-	-
Barrier	R	-	-	-	R	-	-
Beaver	R	R	-	I	-	-	I
Heinrichs	R	-	-	-	-	-	-
Impact	R	-	-	-	I	-	-
Oneida	I	-	-	-	-	-	-
Pacer	R	-	-	-	-	-	-
Peace	S	-	-	-	-	I	S
Primal	I	-	-	-	-	-	-
Profit	I	-	-	-	I	-	-
Rambler	I	-	-	-	-	-	-
Rangelander	S	-	-	-	-	-	-
Roamer	R	-	-	I	-	I	-
Stampeder	R	-	-	-	-	-	-
Spredor 2	R	-	-	-	-	-	-
Sure	R	-	-	-	-	-	-
Thor	R	-	-	R	-	-	I
Trek	R	-	-	I	-	-	S
Trumpetor	R	-	-	-	R	-	-
Vernal	R	R	-	I	-	-	I
120	R	-	-	-	-	-	-
532	R	-	-	-	-	-	-

R=Resistant, I=Intermediate, S=Susceptible, -=Reaction unknown

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