COMMERCIAL

Vegetable Production on the Prairies

Alberta

Commercial Vegetable Production on the Prairies

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ACKNOWLEDGEMENTS

Project Team Lead/Editor

Robert Spencer – Alberta Agriculture and Rural Development (AARD)

Project Team (Project Planning)

Connie Achtymichuk – Saskatchewan Ministry of Agriculture (SK Ag)

Belinda Choban – AARD

Brent Elliott – (formerly with Manitoba Agriculture, Food and Rural Initiatives – MAFRI)

Dr. Ken Fry – Olds College

Betty Birch – (formerly with AARD)

Brian Hunt – Manitoba Agriculture, Food and Rural Development (MAFRD)

Dr. Ron Howard – (formerly with AARD)

Dr. Philip Northover – (formerly with Manitoba Agriculture, Food and Rural Initiatives – MAFRI and SK Ag)

Dr. Doug Waterer – University of Saskatchewan (U of S)

Writing/Review

Connie Achtymichuk – SK Ag

Brent Elliott

Dr. Ken Fry – Olds College

Tom Gonsalves – MAFRD

Dr. Michael Harding – AARD

Brian Hunt – MAFRD

Dustin Morton – AARD

Dr. Philip Northover

Robert Spencer – AARD

Dr. Doug Waterer – U of S

Manuscript Editing

Carolyn King

Other Contributions

Jackie Bantle – U of S

Kathy Bosse – AARD

Dr. Jim Broatch – AARD

John Gillmore – AARD

Justin Schaeffer – U of S

Gillian Spencer

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CONTENTS

Transplant Production

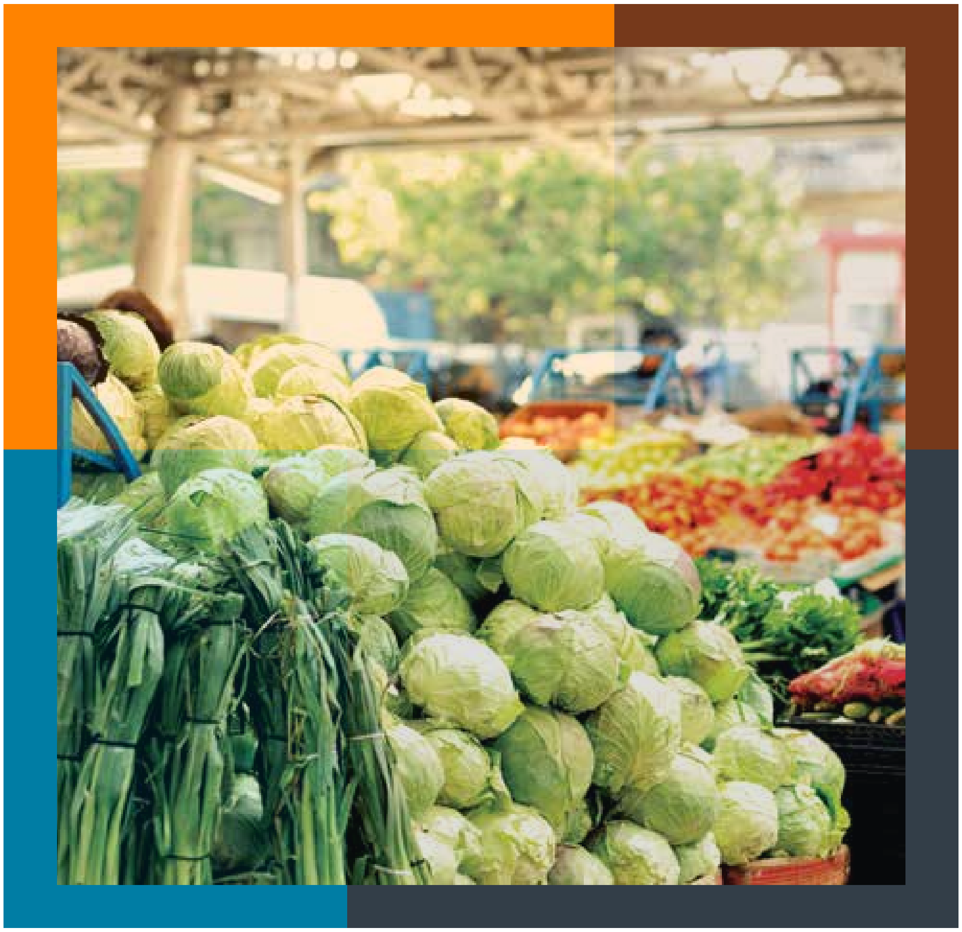
Pest Management

Business Management

Vegetable Production Recommendations

Appendix

INTRODUCTION



INTRODUCTION

Commercial vegetable production on the Canadian Prairies is a diverse industry. Operations range in size from small market gardens growing an assortment of vegetables to large commercial farms producing specific vegetables.

The types and varieties of vegetable crops grown and the practices used vary from operation to operation and region to region. To be successful, vegetable growers need to follow effective production practices and sound business management practices.

Purpose of this manual

This manual provides a comprehensive resource and reference tool for both new and experienced producers at all scales of commercial vegetable production on the Prairies.

The book begins by looking at planning considerations when developing a vegetable production business. Then, it describes vegetable crop production practices from seeding and transplanting to harvesting and storage, including such topics as fertility and irrigation.

Specific chapters on transplant production and pest management provide focused discussion on these important aspects of vegetable production.

A further chapter considers business issues including labour, risk management and marketing. Growing the vegetables successfully is only one aspect of a business; the next steps also need to be planned and handled well.

The greatest detail on the individual vegetables themselves appears in the vegetable production recommendations chapter. Vegetables are grouped in categories allowing a logical discussion of characteristics, growth habits, fertilization, pest management and harvesting.

Finally, because a knowledge of vegetable production can involve the use of some specialized terms, the book provides a glossary of key technical terms used in the text. An appendix also lists sources of further information for growers seeking other references.

Vegetable growers will need to adapt the information in this book to the needs of their own operation. Attending field days, workshops and conferences, networking with other producers, researching information online and doing on-farm trials to test new varieties and practices can all help in learning and sharing knowledge.

Manual origins and foundations

Creating this manual was made easier because of the strong foundation provided by the previous edition called *Alberta Vegetable Production Guide – For Commercial Growers – 1989-1990*. This current book is based on and still has some relevant content from that previous publication. All information has been extensively revised, expanded and updated throughout, but acknowledgement must be made to the work and effort of the authors and contributors of that original manual.

Developing the new *Commercial Vegetable Production on the Prairies* manual has been a long and rewarding process. The hope is that producers find the resource helpful and worthwhile.

GETTING STARTED

Getting Started

Business planning

For anyone starting any business, it is critical to thoroughly develop a comprehensive business plan, including production, marketing and financial aspects. Consider every factor that could potentially affect the success of your business venture and create contingencies to try to mitigate as much risk as possible.

Some factors to consider when starting up a vegetable operation:

- market demand for crop(s)
- potential market channels
- proximity to market
- sources of reliable labour
- state of roads leading from farm location(s) to market
- proximity to and amount of competition
- estimated cost of production
- support of local community
- suitability of the climate for production
- suitability of the land for production

Market research

Before starting any vegetable production operation in any marketing channel, carefully and thoroughly research potential markets to determine the anticipated demand for your projected product(s), as well as competitors, potential issues, challenges, etc. This process can be long and time-consuming, but it will allow you to focus your production for maximum success.

Production costs

Thoroughly investigate the potential costs of production, estimating the anticipated returns based on variable yield and price scenarios for the different crops that might be grown. By having a clearer understanding of the economic factors involved, you can make better decisions on crop choice, scale, etc.

Business plan

You will also need to develop a comprehensive business plan that includes projected revenues, expenses and other components of the business. Clearly outline what you plan to do and how you plan to do things, all the way from growing to marketing.

Periodically review and update your business plan to ensure it is still accurate and appropriate as your operation grows and/or shifts direction. A number of resources are available in different provinces to assist producers in developing and adjusting their business plans (refer to the Appendix at the end of this manual).

Production planning

Success in vegetable production depends on a well thought-out production and marketing plan. Some of the key factors to consider during the planning stage:

- site selection
- water supply and quality
- crop type and variety selection
- market development

If the wrong decision is made regarding any of these key factors, the operation may fail.

The following section covers site selection issues to consider when planning for commercial vegetable production. Other key information in the book appears as follows:

- water considerations, see the Water, Irrigation and Irrigation Management sections in the Field Production chapter
- crop planning, see the Crop Planning section, in General Crop Production, also in the Field Production chapter
- specific crop options, see the Vegetable Production Recommendations chapter
- market development information, see the Marketing section in the Business Management chapter

Site selection

The land selected for growing crops is one of the most important factors in the success of a field vegetable operation. It is the base on which all the other factors are built. The information you gather before selecting a final site will assist in decision-making, both about site selection and during ongoing crop production.

Whether you are planning to buy or rent new land or use your current fields, carefully evaluate each possible field. Poor quality, unsuitable land or land with limitations or issues will contribute potentially insurmountable production barriers to the operation. Sometimes, it is easier to walk away from a poor quality piece of land and find something better than to try to deal with that land's inherent issues.

The key factors to consider when evaluating possible sites for vegetable production:

- field history
- field topography
- shelter
- soil information
- access to water

Field history

Field history is the record of the different operations and activities on a particular field. These operations may or may not have a bearing on the subsequent crops. When investigating a field's history, consider past crop rotations, pesticide and fertilizer applications, other soil amendments, tillage and irrigation practices.

Crop history

Knowing which crops have been grown on a piece of land in the past can help in making management decisions in the present and in determining the land's potential suitability for different crops. Past crops can influence soil salinity and/or fertility levels, potential insect, disease and weed pressures as well as possible pesticide residues and product efficacy. The performance of past crops can also give an indication of whether certain crops will likely do well on that piece of land.

Pesticide applications

Pesticides (fungicides, insecticides, herbicides, etc.) vary in how long they persist in the surrounding environment, including the soil or water, and whether they might affect subsequent crops. While residual insecticides and fungicides typically will not harm crop growth, they may affect the types of pests present or may potentially show up as a residue in subsequent crops.

Herbicides, particularly soil-applied products with long residual activity, can have a significant effect on subsequent crops. Knowing a field's herbicide history going back 3 to 5 years lets you know about possible residue concerns. If dry conditions occurred during any of those years, try to extend the history by a further 1 to 2 years because chemicals break down more slowly in dry conditions due to reduced soil microbial activity. For more information on herbicides and herbicide residues, see the section on Weed Management in the Pest Management chapter.

Knowing the pesticide application history for adjacent pieces of land is also useful as some products will move in soil water or may have been misapplied (drift, etc.).

Fertilizer applications

Information on the types, amounts and timing of past fertilizer applications will provide a basic understanding of the general residual fertility levels in the field. This can affect which crops can be grown, as well as how much nutrients may need to be added. Excess residual nutrients can affect crop health and productivity. Soil testing is recommended for more detailed information on soil fertility (see Soil Testing in the Fertility section, Field Production chapter).

Manure applications or other soil amendments

Knowing about other soil amendment applications helps in understanding current soil conditions in the field. For example, details about animal manure applications, such as the source of the manure, whether it was composted and to which crop(s) the manure was applied, are useful. Similarly, information about past green manure practices (when a crop is ploughed into the soil as a source of organic matter) is also helpful.

Manuring practices influence soil organic matter and soil fertility levels, which will influence production management decisions. Organic matter plays an important role in improving soil structure and health, which will affect crop health. Excessive organic matter levels or untimely applications of manure or other amendments can negatively affect crop fertility regimes.

Tillage and soil conservation practices

Tillage and soil conservation practices can affect a field's general productivity and suitability for production. Excessive tillage can lead to soil erosion, which reduces productivity. Reduced and zero tillage systems protect the topsoil, conserving soil organic matter and fertility. If a field has been rototilled for years, a hardpan layer may have developed, leading to poor root health.

Irrigation practices

The amount and quality of irrigation water applications to the site will affect soil quality. For example, irrigating with water high in salts may lead to higher than recommended soil salinity and reduced crop productivity.

Field topography

Field topography refers to the overall physical characteristics of the field:

- slope steepness
- soil depth
- water and air drainage
- presence of stones and surrounding vegetation

These characteristics can have a significant influence on crop production and management.

Ideally, fields for vegetable production should be nearly flat to slightly sloping, well drained and relatively free of large stones and low areas. Crop maintenance efficiency, irrigation and harvest operations are greatly enhanced in fields with this type of topography.

It is rare to find a completely level piece of land. Land will often undulate somewhat or may slope off in one direction. Some slope may be beneficial as it promotes natural air movement off a field, which can help protect a crop from frost, for example. Slope also helps move water off a field or at least prevents the water from settling in one area.

Avoid sites with slopes equal to or greater than 1.5 per cent (45 centimetres (cm) elevation change per 30 metres (m); 18 inches (in.) per 100 feet (ft.)). They are prone to excessive erosion.

Poorly drained fields or those with low areas can become waterlogged following heavy rain or spring runoff. Poorly drained areas interfere with all aspects of field preparation and management. Crop health is also impaired in wet spots.

Vegetable producers with heavier clay soils can use raised beds to improve drainage, reduce yield losses and improve crop quality.

Surrounding vegetation, whether it is crops, pastures or wild plants, could harbour insect pests and plant diseases, but it may also host beneficial insects.

Stones interfere with land preparation and crop establishment. They are particularly troublesome during the mechanical harvest of root crops.

An artificial shelterbelt at an irrigation demonstration farm in Lethbridge, Alberta
Photo: Troy Ormann

Shelter

Wind damage is a consistent problem for vegetable growers on the Prairies. Winds can cause soil erosion, particularly on the coarse-textured soils preferred for vegetable crops. At the same time, the low levels of crop residue that typically remain after vegetable crops make soils more prone to erosion.

Windy conditions dry the soil while also interfering with irrigation applications or spraying chemicals. Wind can physically damage plants by knocking them down or by causing portions of a plant to bang or rub against each other, leading to bruises and blemishes.

Shelterbelts are an important addition to any land. Shelterbelts slow down prevailing winds and allow snow to accumulate. Shelterbelts can create a unique and beneficial microclimate, potentially allowing earlier spring planting in some areas, resulting in earlier harvests and higher returns. Permanent shelterbelts of trees and shrubs provide very effective wind protection, but they take time to develop. Semi-permanent, annual plantings or wind fences/barriers are quicker and more mobile systems of wind protection.

Shelterbelts, while slowing prevailing winds, should not be a solid barrier to all air movement. Some airflow will help move cool air off of fields. Stagnant air will increase relative humidity, which can increase the incidence of diseases like powdery mildew.

Soil information

Soil quality is fundamental to all agricultural production systems but is particularly important for vegetable crops due to their high value and their sensitivity to poor soil quality. Table 1 lists important soil quality properties affecting soil productivity.

These properties influence a soil's ability in several ways. Can the soil do the following:

- provide an optimum medium for crop growth?
- sustain crop productivity?
- maintain environmental quality?
- provide for plant and animal health?

Therefore, the maintenance of soil health and quality is the primary long-term management goal for successful vegetable production. Unfortunately, too often, too little time is spent in selecting soil type and soil management practices.

Soil type refers to the general physical composition or properties of the soil. Soil consists of a mineral fraction (sand, silt and clay), an organic matter fraction (living and decomposing), air and water. Optimum vegetable production is achieved on well drained, sandy loam soils with over 2 per cent soil organic matter content.

Although vegetables can be grown on a wide range of soil types, most vegetables are not well adapted to heavy clay soil. Clay soils tend to have poor aeration and drainage, so they can restrict root growth. Consequently, avoid these soil types.

Soil testing

Before using a new field or even a known field for vegetable production, be sure to gather detailed soil information through soil testing. Even fields that have had identical production practices or look very similar on the surface can vary significantly in terms of soil quality and potential productivity. Soil testing can bring to light various critical limitations, and the results provide detailed baseline information for site and crop management decisions.

Soil testing involves the random collection of soil samples from locations across a field. Samples are collected from similar depths and then bulked together. From that bulk source, a uniform, homogenized sample is submitted for testing at a laboratory.

Based on the anticipated rooting depths for your proposed crops, choose from the following options for soil sampling depths:

- shallow rooting depth (0 to 15 cm; 0 to 6 in.)
- entire main rooting zone (0 to 30 cm; 0 to 12 in.)
- entire main rooting zone divided into two parts (0 to 15 and 15 to 30 cm; 0 to 6 and 6 to 12 in.)
- deep rooting zone (30 to 60 cm or 12 to 24 in.), recommended when perennial or deep-rooted vegetable crops are being considered

For first-time field use, consider sampling from the entire root zone (0 to 60 cm; 0 to 24 in.) regardless of the crops planned. However, collect and submit the sample as two parts (0 to 30 cm and 30 to 60 cm; 0 to 12 in. and 12 to 24 in.).

Abnormal areas within the field (areas not characteristic of the majority of the field) should be sampled and tested separately.

Soil tests provide valuable information on the following:

- Soil texture (per cent sand, silt and clay within a soil) affects drainage, rate of spring warming, water-holding capacity, etc. (see Figure 1).

Table 1. Soil quality indicator properties

Physical	Chemical	Biological
Bulk density	Acidity or alkalinity (pH)	Microbial biomass carbon
Rooting depth	Electrical conductivity	Earthworms
Water infiltration rate	Cation exchange capacity	Enzymes
Water-holding capacity	Organic matter	Disease suppressiveness
Aggregate stability	Mineralizable nitrogen	
	Exchangeable potassium	
	Exchangeable calcium	

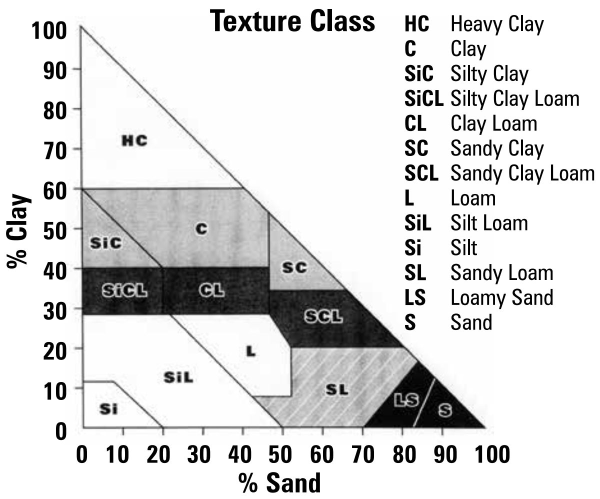


Figure 1. Soil texture triangle

- Soil salinity (electrical conductivity) affects suitability for crop production – it is important to know which type of test was used to determine soil salinity (e.g. saturated paste test or 1-to-1 soil-to-water extraction tests) as the test values are not comparable.
- Soil organic matter influences soil fertility, water-holding capacity and chemical usage.
- Soil pH (measure of soil acidity or alkalinity) influences nutrient availability to plants and can directly affect some crops.
- Soil fertility (nutrients) affects crop growth and productivity.

Soil testing can be done either in the fall just prior to the ground freezing or early in the spring before working the fields.

Access to water

Consistent access to adequate supplies of high quality water is critical to vegetable crop production. A lack in either water quantity or quality cannot be offset by an ideal field site and desirable soil type.

Water is used for irrigation and for washing and preparation of vegetable crops for sale. A permit will likely be required before water can be used for irrigation. Check with local irrigation or water supply personnel for appropriate procedures.

To achieve a reliable, consistent supply of high quality vegetables, irrigation is a must on the Prairies. Even in areas where rain is relatively plentiful, irrigation improves crop yields and quality as well as the predictability of yields and quality. These benefits are achieved because irrigated crops receive adequate moisture when they require it. A lack of irrigation marginalizes production potential and may limit the types of markets that can be entered (e.g. commercial wholesale).

Water quantity

Vegetable crops generally require more total water and more consistent soil moisture levels than most field crops. Therefore, only fields that have ready access to an abundant water source should be considered for vegetable production. The water source should have the capability to provide the volume required for the maximum needs of the highest water-using crop to be planted.

The amount of water required will depend on these factors:

- crop types to be grown
- soil type(s) within the field(s)
- precipitation received during the growing season
- winter moisture carry-over
- type and efficiency of the irrigation system being used
- climatic variables such as temperature, relative humidity and wind

Water quality

Water quality is as important as water volume in selecting a field site water source. A number of water quality properties need to be evaluated to determine a water source's suitability for use in vegetable production.

Water sources for vegetable irrigation should contain less than 400 parts per million (ppm) of soluble salts, so that soils do not accumulate salts and deteriorate in quality and productivity. A knowledge of crop tolerance to salinity is essential if marginal quality water is to be used. Tables 2 and 3 classify irrigation waters in terms of salinity and sodium characteristics.

Table 2. Permissible salinity limits for classes of irrigation water

Water class	Total dissolved solids		Sodium	Chlorides (Cl) (meq/L)	Sulphates (SO_4) (meq/L)
	Electrical conductivity (μmhos)	Gravimetric (ppm)	(Na) (%)		
Class 1 (excellent)	250	175	20	4	4
Class 2 (good)	250 - 750	175 - 525	20 - 40	4 - 7	4 - 7
Class 3 (permissible)	750 - 2,000	525 - 1,400	40 - 50	7 - 12	7 - 12
Class 4 (doubtful)	2,000 - 3,000	1,400 - 2,100	60 - 80	12 - 20	12 - 20
Class 5 (unsuitable)	3,000+	2,100+	80+	20+	20+

Adapted from: Guidelines for Irrigation Water Quality and Water Management in the Kingdom of Saudi Arabia: An Overview. G. Hussain, A. Alquwaizany, A. Al-Zarah. 2010. J. of Applied Sciences.

Also, avoid water sources containing high levels of potentially toxic elements, such as heavy metals, as these elements tend to accumulate in the crop and represent a toxic hazard for consumers. The presence of harmful organisms (e.g. *E. coli*) or other contaminants that can affect health and safety should also be assessed and considered when choosing a water source. Concerns over water-related on-farm food safety issues have increased significantly in recent years.

Abundant, year-round supplies of high quality water may also be required for cooling the crop after harvest and for washing the crop before marketing. To safeguard consumer health, quality standards for the water used for washing vegetables are very high. For On-Farm Food Safety (OFFS) resources, see the links in the Resources section of the Appendix, or consult with your local OFFS contact.

Water sources

Water for irrigating and washing the crop can be obtained from lakes, rivers, streams, dugouts and wells. Be sure the water source will meet your water quantity and quality needs and that you can legally use the water.

You may need to create or develop a water source to supply your irrigation needs. There are costs associated with water source development (e.g. dugouts, wells). Before developing a water source, consult an agricultural water specialist or engineer for assistance to ensure the completed water source will meet your projected needs.

Legal access to water varies. Physical access to a water source DOES NOT come with the right to use the water for crop production. Be sure to contact your provincial regulatory bodies to determine the correct process to gain the right to use water from a particular water body. This process can take time to complete. There is usually a cost associated with water licensing (for more information, see the Water Licensing section in the Field Production chapter).

Table 3. Classification of sodium hazard of water based on sodium adsorption ratio (SAR) values

SAR values	Sodium hazard of water	Comments
1-10	Low	Use on sodium-sensitive crops requires caution
10-18	Medium	Gypsum and leaching needed
18-26	High	Generally unsuitable for continuous use
26	Very high	Generally unsuitable for use

Adapted from: Irrigation Water Quality Standards and Salinity Management Strategies. Website: soiltesting.tamu.edu/publications/B-1667.pdf

FIELD PRODUCTION

Field Production

Introduction

This chapter describes production practices for vegetable crops on the Prairies:

- crop planning
- fertility
- seeding and transplanting
- water and irrigation
- growing season extension
- harvesting and post-harvest management
- storage

Transplant production and pest management will be handled separately in more detail in the chapters following the Field Production chapter.

General crop production

Crop planning

To achieve maximum productivity and profitability, select crops that will yield well, will mature within the average growing season and are in demand in the chosen market. When planning your crop rotation, consider the various needs of each proposed crop in relation to previous and subsequent crops. Also consider possible pest issues, pesticide carry-over, changes in market demand and new crop opportunities.

Consider all crops when planning your production schedule. Certain crop choices might help with the timing of your operation's equipment, labour and facility requirements. For instance, each year you might grow some crops that can be seeded early and some that can be seeded later.

Rotations

As much as possible, avoid growing the same or closely related crops on the same field or area year after year. Rotations to non-host crops can significantly reduce the severity of disease and/or insect pest problems over time. A rotation of 3 to 4 years between similar crop types is generally recommended.

Rotation options may include broadleaf crops of different types, grassy crops, summerfallow, green manure crops, etc. Alternating between crop types allows you to change the depth of tillage, improve the control of weeds, diseases and insect pests as well as improve other factors.

Variety selection

New and improved varieties or cultivars of vegetables are released annually by breeders across the world. Improved characteristics may include increased yield, better disease or insect resistance, improved flavour, superior storage potential and so on. Not all varieties or cultivars are suitable for production on the Prairies.

You can consult various sources to select crop types and cultivars for your farm.

Seed catalogues

A simple option is to peruse seed catalogues or other publications that list the characteristics of cultivars available from the various seed companies. Descriptions of basic factors such as yield, days to maturity or other specific requirements or qualities are typically included in such publications. Be very cautious when using these descriptions as climatic variations may significantly affect both quality and yield of the cultivars.

Seed company representatives

Most seed companies have sales representatives who can be consulted regarding the newest varieties, including production recommendations, expected performance in a particular area and potential production issues that might be expected.

Public research
In the past, public institutions put significant effort into testing and evaluating new varieties/ cultivars for producers. Varietal evaluations by universities or provincial government researchers provided annual comparisons of new materials tested in different conditions (soil types, moisture regimes, etc.) and regions.

Funding for this type of research has waned in recent years. However, some testing is still done each year and past research can also be found. This type of information is useful in weeding out potentially poor selections before on-farm testing.

Other producers' experiences
Checking with fellow producers about their experiences with different crops or varieties can also be useful. Consider which conditions (soil, moisture, growing season length, etc.) on their farms are similar to yours to assess the degree of applicability of the information to your own situation.

On-farm trials
Trying a small amount of a new crop or variety/ cultivar on your farm is an effective way to find new potentially profitable cropping opportunities. Consider planting a row or strip or two of different cultivars and then comparing them to tried-and-tested varieties. On-farm trials are the best test of a cultivar's suitability for a specific farm or field.

University of Saskatchewan bean variety trials
Photo: Robert Spencer

Customer requests
In a market-driven system, the customer can exert a significant influence over the crops grown. If a customer wants a given cultivar and is prepared to pay for it, then consider growing it, even if it is not the strongest performer.

For example, some crops are often in demand, such as banana potatoes, Copenhagen cabbage and most heirloom tomatoes. However, these crops all have limitations that need to be addressed before committing to produce them.

Frost-free period
The length of the growing season is essentially the time between the last spring frost and the first fall frost. This period is a key determinant for what will and what will not grow on your farm.

The frost-free period can vary from year to year; however, the long-term average for your area provides a general idea of the length of time you have to get each crop to mature and whether options to deal with a very short frost-free period might be needed.

For instance, frost-tolerant crops (i.e. crops that can handle some frost and continue growing) or growing season extension techniques (e.g. high tunnels, crop covers, etc.) allow an increase to the growing season.

Predicting crop maturity
Knowing the number of days that a specific crop takes to reach maturity allows you to plan for harvesting and marketing. Days to maturity are characteristic of each crop and variety/cultivar and can be further influenced by temperature, moisture/precipitation, sunlight, crop health, etc.

By taking into account the influence of these factors on maturation, you can more closely predict harvest dates for some crops and the availability of a crop to be marketed. Examples of models for predicting crop maturity based on temperature include Corn/Crop Heat Units and Potato Degree Days.

All crops have a base air temperature value below which the crop does not significantly grow. This base value varies between crops

(Table 4). Growth increases as temperatures increase above the base temperature until an optimum temperature is reached. If temperatures exceed the optimum, growth and quality may be compromised. By tracking the number of hours the temperature is above this base value, producers can estimate a cumulative total of time the crop is growing.

Table 4. Base temperatures for crop growth

Crop	Base temperature (°C)	Base temperature (°F)
Asparagus	5	41
Beans	10	50
Beets	5	41
Carrots	3	37
Cole crops (broccoli, cabbages, cauliflower, etc.)	5	41
Corn (sweet)	10	50
Cucumbers	15	59
Lettuce	5	41
Melons, squash	10-12	50-54
Onions	2	36
Peas	5	41
Potatoes	5	41
Solanaceous crops (eggplants, peppers, tomatoes)	10-15	50-59

Crop Heat Units

Cumulative temperatures such as Crop Heat Units (CHU) are closely related to crop development. CHU are a more accurate way to measure a crop's progress through its physiological stages than by using calendar days because in warmer regions, more CHU accumulate per day than in cooler regions, resulting in a crop that develops more rapidly.

Calculating the CHU for a crop involves several considerations. Day and night temperatures are treated separately. It is assumed that no growth occurs when night temperatures are below 4.4°C (40°F) or day temperatures are below 10°C (50°F). Maximum growth occurs at 30°C (86°F), and the growth rate decreases when temperatures go above 30°C (86°F).

CHU are calculated using the following formula:

$$CHU_{day} = 3.33 \times (T_{max} - 10) - 0.084 \times (T_{max} - 10)^2$$

$$CHU_{night} = 1.8 \times (T_{min} - 4.4)$$

$$CHU = [CHU_{day} + CHU_{night}] / 2$$

where T_{min} = daily minimum temperature (°C) and T_{max} = daily maximum temperature (°C)

Most corn hybrids sold in Canada are given a CHU rating. This rating can be used as a base for selecting hybrids suited to the average annual CHU in your area. The development of each plant is controlled by its genetic makeup and how these genes react to the environment in which the plant is growing.

Fertility

There are 17 essential nutrients required for plant growth:

- carbon (C)
- oxygen (O)
- phosphorus (P)
- sulphur (S)
- magnesium (Mg)
- manganese (Mn)
- copper (Cu)
- molybdenum (Mo)
- nickel (Ni)
- hydrogen (H)
- nitrogen (N)
- potassium (K)
- calcium (Ca)
- iron (Fe)
- zinc (Zn)
- boron (B)
- chlorine (Cl)

With the exception of carbon, hydrogen and oxygen, all these nutrients are taken up as mineral elements from the soil.

The mineral nutrients are divided into two groups: **macronutrients** (N, P, K, S) that are required by plants in relatively large amounts and **micronutrients** (Ca, Mg, Fe, Mn, Zn, Cu, B, Mo, Cl and Ni) that are required by plants in relatively small amounts.

An insufficient supply of any one or more of these 17 nutrients can harm plant growth and decrease yields, which is why soil testing is a recommended practice.

Soil testing

Fertilizer requirements vary from field to field and from year to year. Soil testing before planting takes the guesswork out of fertilizer decisions. Testing allows fertilizer recommendations to be based on a comparison of the crop's nutrient requirements relative to the soil nutrient levels as indicated by the soil test.

This analytical approach leads to more efficient nutrient management because it helps you prevent nutrient deficiencies while avoiding wasteful and damaging over-applications. General fertilizer recommendations for a crop should only be used if a soil test is not available.

Soil test recommendations are generally well understood for the macronutrients nitrogen, phosphorus, potassium and sulphur, as well as the micronutrients magnesium, calcium, zinc and boron. You can use a combination of soil testing and tissue analysis (see following Plant Tissue Analysis section) to fine-tune your nutrient applications.

On new fields, soil testing can provide benchmark fertility and soil quality information, which can help you anticipate how a field will perform or whether it is suitable for specific vegetable crops. Regular soil testing also allows you to track gradual changes in soil quality characteristics and soil fertility levels, so you can adjust cropping and fertilizing practices each year.

Yields and economic returns from fertilizers can be optimized, and potential soil and water pollution minimized, if fertilizer applications are carefully matched to the needs of a particular crop grown on a specific field.

An effective soil testing program is one in which every field is tested every year. This approach provides an inventory of the nutrient levels in each field, plus specific recommendations as to the kinds and rates of fertilizer nutrients to apply for each crop. Recommendations may be based on specific times and methods of application.

One approach used to make recommendations based on soil testing is the "sufficiency level" approach. This approach is built on the concept that certain levels of plant nutrients in the soil are defined as optimum for each crop. Usually a crop will respond positively to an application of a specific nutrient if the soil test value for that nutrient is below its optimum level. Yield responses will be limited as soil nutrient levels approach or exceed the optimum.

Another approach to soil testing and soil fertility management is called the Base Cation Saturation Ratio (BCSR). This approach revolves around the concept of "balancing" soils based on certain cations (e.g. Mg^{2+}, Na^{+}, K^{+}, Ca^{2+}) and the ratios in which they occur. This is a complex approach, and a great deal of information is required.

Many private soil testing facilities conduct soil analyses. Soil tests generally report macronutrient levels, soil texture, soil pH, soil salinity and, if requested, soil organic matter. Micronutrient testing is not typically part of standard tests and must be specifically requested.

Basic soil sampling procedures

When collecting soil samples, follow these general guidelines:

- Typically, soil sampling is done in the fall after soil temperatures drop below 5°C (41°F) or in the early spring. To benefit most from the soil test information, conduct soil sampling before planting.
- Collect separate samples for each field on your farm.
- For each field, collect multiple samples from across the field and combine them into one bulk sample, and then take the final sample from the bulk sample. A common field sampling technique is to use a zigzag pattern.

- The point of soil sampling is to get a representative sample for each field. If the field contains unusual or abnormal areas such as wet or waterlogged areas, areas where fertilizer spills have occurred, areas with high levels of applied manure, low spots, eroded knolls, areas with heavy crop residues, etc., these areas should be sampled and analyzed separately.
- Collect separate bulk samples for the various soil depths, for example, shallow rooting depth (0 to 15 cm; 0 to 6 in.), standard rooting depth (0 to 30 cm; 0 to 12 in.) or deep rooting depth (30 to 60 cm; 12 to 24 in.). Choose your sample depths based on the anticipated crop rooting depths. Submit a sample from each bulked sample to the lab for testing.
- Keep samples cool (refrigerated or out of warm areas) and free from contaminants. Deliver samples to the soil testing lab as soon as possible.

Soil nutrients measured in a soil test

The main nutrients likely to be lacking in most Prairie soils are nitrogen, phosphorus and to a lesser extent, potassium and sulphur. Few soils are so deficient in one or more of these macronutrients that severe (obvious) deficiency symptoms develop in the plants. Slight nutrient deficiencies are less obvious and may develop periodically. Micronutrient deficiencies are rarely documented.

Nitrogen

Most plants are capable of using both the ammonium (NH_4+) and nitrate (NO_3-) forms of nitrogen (N) in the soil, but they prefer the nitrate form. Nitrate-nitrogen (NO_3-N) levels vary considerably from field to field and year to year because of differences in soil types, weather conditions, management practices and shifts in nitrogen forms within the soil.

The nitrogen analysis in soil testing measures plant-available nitrogen (nitrate) in the soil at the time of sampling. Soil nitrate levels vary, due in part to the movement of nitrogen in and out of its various forms in the soil. This movement is most rapid when soils are warm and moist. Therefore, to accurately assess the nitrogen status of the soil, take soil samples in late fall or early spring when fewer changes in nitrate-nitrogen will occur.

Nitrate-nitrogen moves readily within the soil in the soil moisture. On irrigated soils in particular, take soil samples down to a depth of 60 cm (24 in.) to accurately assess the level of available nitrogen. For more information, see the soil sampling guides provided with your soil testing kits.

In addition to the nitrogen available in the soil at planting, nitrogen is released by the soil during the growing season (mineralization), called residual nitrate. Residual nitrate levels tend to be higher in fields following the more heavily fertilized row crops, such as potatoes and corn, as compared to the less heavily fertilized, solid-seeded cereal and oilseed crops.

Fields that have been heavily manured, repeatedly fertilized with high rates of nitrogen and/or affected by drought or some other factor that has severely restricted yields often contain higher than average residual nitrate levels. This information must be supplied with the soil samples so that nitrogen fertilizer recommendations can be adjusted accordingly.

Most Prairie soils require some nitrogen fertilizer for vegetable crop production. Stubble fields do not generally contain sufficient available nitrogen for optimum vegetable crop production. Fallow fields contain somewhat more available nitrogen than stubble fields, but not likely enough for vegetables. Fields where a green manure crop was worked in or fields in which a crop was ploughed down because of drought, severe insect damage or hail usually contain higher nitrate levels than stubble fields, but lower than fallow.

Following breaking (termination) of perennial legume stands, soils will release considerable quantities of nitrogen, which may supply a portion of the nitrogen requirements of the subsequent crop. Grass and grass-legume breaking provides a lower, but substantial level of nitrogen for crops that follow. The amount of nitrogen available is determined by the stage of legume forage crop termination and density of the legume stand.

Research in Manitoba has shown that either tillage or herbicide termination of the stand are equal in releasing nitrogen for subsequent crops.

Although fallowing has a short-term positive effect on a field's nitrogen status, in the long term, summerfallowing degrades soil quality and leaves the soil susceptible to erosion. Therefore, except for certain emergency situations, summerfallowing is NOT a recommended practice in the Prairies.

Tillage operations during fallow periods should leave sufficient stubble cover to prevent soil erosion. Poorly maintained summerfallow or fields that have been broken or ploughed down late in the season usually contain available nitrogen comparable to or lower than stubble fields.

Phosphorus

Unlike nitrogen, the level of available phosphorus (P) in a particular field does not change dramatically within the growing season or from year to year in response to weather conditions, crop rotations or crop management practices unless very high rates of phosphate fertilizer or manure are applied. A soil test for phosphorus can be used as a guide to phosphate fertilizer requirements for 2 to 3 years. Periodic evaluation of the soil phosphorus level will provide a useful guide to changes in this nutrient over a period of time.

The majority of Prairie soils cannot supply adequate P for optimum yields of vegetable crops, so P applications are usually required. However, fields that have been repeatedly manured tend to have high levels of P, especially if the manure is being applied at rates sufficient to meet a significant portion of the crops' N requirements. In this situation, soil P levels may build up to the point where producers need to be careful about the environmental effect of runoff from these fields into waterways.

Potassium

Like phosphorus, potassium (K) levels do not generally change significantly over the course of the growing season or from year to year in response to weather conditions or crop management practices. Periodic soil tests will provide an assessment of changes in the potassium level in the soil over time.

Most Prairie soils contain sufficient K for vegetable crop production; however, there are exceptions. Test each field as it is brought into production. Soils likely to be low in K are coarse-textured sands, sandy loams and organic soils.

Whether a soil has sufficient potassium for a planned crop will depend on the crop type. For example, some sandy soils may be deficient in K for potatoes, which have a very high potassium requirement. Use a soil test to identify a need for potassium fertilizers in a crop rotation.

Sulphur

Some Prairie soils may be deficient in sulphur (S), particularly for crops with a high S requirement like *Brassica* crops (e.g. canola, cabbage). Sulphur deficiencies are most frequently found on well drained and Grey Wooded soils.

Soil testing is the best available tool for determining S fertilizer needs. Testing should be done to a 60-cm (24-in.) depth to account for sulphate (SO_4^{-2}) not at the surface but still available for deep-rooted crop use. Soil tests may not routinely include sulphur; therefore, ask that this test be included if your soils are typically low in sulphur or if you are unsure of the sulphur content.

Sulphate concentrations within a field can vary greatly, depending on soil type (sand versus clay) and slope position. It is not uncommon for some areas within a field (e.g. low lying, heavy soils) to contain many times more sulphate-sulphur than other areas. Sampling a variable field as a whole would typically result in a recommendation that no sulphur fertilizer is needed, yet crop plants in some areas of the field may be highly S-deficient. For this reason an "insurance application" of sulphur fertilizer may be advisable on variable soils or where high value, high sulphur-demanding crops, such as the *Brassica* vegetable crops, are to be grown.

Available sulphate levels are often low following the breaking of a perennial legume or grass-legume stand due to the high sulphur removal rates of these crops.

Micronutrients

Micronutrients are essential plant nutrients that are required in relatively small amounts. They include boron (B), calcium (Ca), chloride (Cl), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn). Some micronutrients, such as Ca and Mg, are found in higher concentrations in plant tissues and are required in much higher amounts than the other micronutrients.

In the Prairies, most soils have adequate supplies of micronutrients to meet the needs of vegetable crops. However, the following soil and environmental conditions may contribute to a reduction in micronutrient availability:

- Soils low in organic matter may be deficient in B, Cu and Zn.
- Sandy soils (coarse-textured) are more likely to be deficient in Cl, Cu, Zn, B and Mo than clay soils (fine-textured).
- Peat soils or soils with over 30 per cent organic matter tend to be deficient in Cu, Mn and B.
- Cool, wet soils reduce the rate and amount of micronutrients that can be taken up by the crop.
- High soil pH reduces availability of all micronutrients except Mo.
- Highly calcareous soils with high lime content tend to be deficient in Zn and Fe.
- Soils with exposed subsoil due to erosion or land levelling tend to be deficient in Zn.
- Excessive soil phosphorus levels can render Zn unavailable to the crop.

Certain crop types and even certain varieties may be especially sensitive to micronutrient deficiencies. Highly responsive crops often respond to micronutrient fertilizer if the micronutrient concentration in the soil is low. Moderately responsive crops are less likely to respond, and non-responsive crops do not usually respond even at the lowest micronutrient levels.

In general, the degree of crop response to micronutrient fertilizers on the mineral soils typically found on the Prairies has been small.

Soil pH

Soil pH is a measure of the acidity or alkalinity (basicity) of a soil. It describes the concentration of hydrogen ions (H+) or the ratio of hydrogen ions (H+) to hydroxide ions (OH-) in the soil solution.

Soil pH is measured on a scale of 0 to 14, with 0 being acidic and 14 being alkaline. Soils with a pH of 6.5 to 7.5 are considered neutral, and most vegetables grow well in this pH range. Soils of pH 6.0 or less are considered acidic. Soils with a pH of 7.5 or higher are said to be alkaline.

The terms “alkaline” and “alkali” should not be confused. Alkali is an old term used to describe soils that are high in sodium salts.

Vegetable crops may not perform as well in acidic or alkaline soils, and soil nutrient availability is negatively affected.

Soil pH conditions result from the soil’s parent material and age, vegetation type and climate (particularly the amount of rainfall). Soil pH varies considerably across the Prairies. Most Manitoba and Saskatchewan soils are neutral (pH 7.0) to alkaline (pH greater than 7.0). Acidic, neutral and alkaline soils can be found in different places in Alberta.

Soil pH influences nutrient availability, microbial activity and agricultural chemical activity as follows:

Under neutral pH:

- Most nutrients are available.

Under low pH:

- *Rhizobium* bacteria are inhibited. These soil bacteria help legumes obtain nitrogen from the air through a process called nitrogen fixation.
- Some micronutrients may be available in toxic amounts (see Figure 2).
- Herbicides in the imidazolinone family (Group 2), such as Pursuit (imazethepyr), break down slowly.

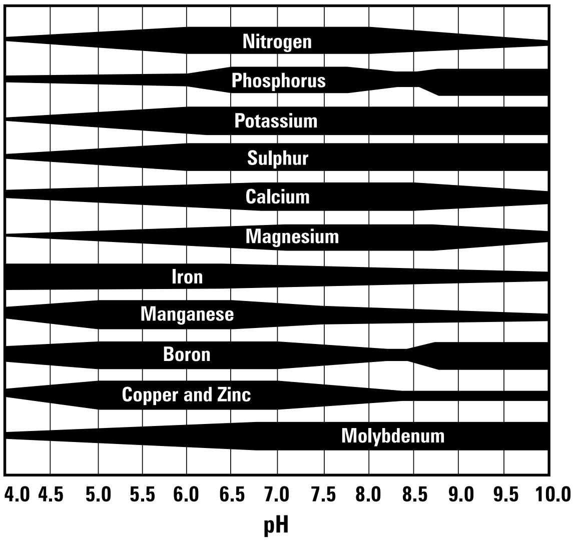


Figure 2: Nutrient availability as affected by soil pH

Under high pH:

- Availability of phosphorus and most micronutrients is reduced. These nutrients will have to be placed close to developing plants or applied via the foliage.
- Losses of urea-based fertilizers to volatilization are greater.
- Risk of plant injury from seed-placed urea is increased.
- Herbicides in the sulfonyl urea family (Group 2), such as Ally (metsulfuron methyl) and Atrazine (triazines), break down slowly, increasing the potential for damage to subsequent herbicide-sensitive vegetable crops.

Management practices may affect soil pH. Slight acidification of soils may occur through repeated application of nitrogen and sulphur fertilizers; however, on more alkaline soils, this effect is typically negligible.

Soil has an incredible buffering potential, making pH adjustment difficult. However, adjustments may be necessary in some situations. Liming (the application of calcium- or magnesium-rich materials such as dolomitic limestone) effectively raises the pH of acidic soils. However, a large amount of material is required to make a small change in pH.

Attempts to acidify alkaline soils are usually unsuccessful since the high calcium carbonate content provides strong neutralization. Changes in pH are not necessarily permanent, as mineral elements can be removed by leaching or other soil processes.

High pH soils may result from salt movement or salinity in the soil and from erosion, tillage or land levelling, which removes or dilutes surface soil with more calcareous subsoil.

Soil salinity

Soil salinity is measured by electrical conductivity (EC), which reflects the ability of a substance to conduct electricity. EC is usually measured in millisiemens/cm (mS/cm). Higher EC values reflect higher levels of salt, either in the soil or in the soil water.

Soil tests may report the levels of sulphates and sodium because they are the primary cause of salinity problems on the Canadian Prairies. Typically, soils with an EC value of less than 1 mS/cm are considered suitable for vegetable crop production. Avoid soils with higher EC values if possible.

Soil salinity is determined using either a saturated paste method or a soil-to-water (1:1) extraction method. Both test methods report results using the same units. However, the values are NOT comparable and can result in significant differences in management recommendations. Saturated paste tests are more expensive but more accurate than 1-to-1 extraction.

Saline soil, often incorrectly referred to as alkali, may be a problem in many parts of the Prairies. Soil salinity is a soil condition where water-soluble salts in the crop rooting zone impede crop growth. Saline soils are often formed in areas where an excess of water rises to the surface and evaporates, leaving behind salts that accumulate near the soil surface. The use of irrigation water that has a high salt content may also cause soil salinity to develop over time.

Soil salinity can be a somewhat transient issue, with values changing over a number of years, particularly when moisture levels fluctuate (e.g. wet years with a high water table versus dry years with a low water table).

Saline soils tend to crust easily and are difficult to till when wet or dry. Severe soil salinity will cause bare, white spots in a field. More moderate levels of soil salinity can harm the growth of salt-sensitive crops such as vegetables. Crops growing in a saline area show reduced growth with leaves that are smaller and darker than normal. Soil salinity may also cause a burning on the edge (margin) of the leaves, and the plants may wilt even when the soil is still moist.

To assess the type of salinity problem, soil from affected and non-affected field areas should be sampled separately. The samples should be analyzed for EC, pH, base cation saturation and content of calcium, magnesium, sodium and organic matter.

High salt content increases the osmotic potential of the soil solution and prevents crop uptake of water. Crops are generally most sensitive to salinity during germination and emergence.

Differences in tolerance to salinity exist between various crops and, in some cases, varieties of the same crop. Vegetable crops are generally considered to be more sensitive to salinity than most field crops; however, there are exceptions. Some crops, such as beets, are sensitive in the seedling stage but become tolerant later. Others, like corn, are salt-tolerant in the seedling stage and become sensitive later.

Table 5 lists salinity tolerances for various vegetable crops from the late seedling stage to early maturity.

It is preferable to grow high value vegetable crops on non-saline soils. If saline soils are used, grow only those crops that are tolerant of the salinity level in the soil.

It may be possible to reclaim saline soils by heavy irrigation of fields equipped with subsurface drainage, but this approach is costly, and a specialist should be consulted before proceeding.

Monitor the long-term effect of irrigation on soil salinity, whether or not the irrigation water tends to be saline. With very saline irrigation applications, soil can quickly become saline. Using slightly salty water could result in a slower development of saline soils. Even when using good, non-saline irrigation water, soil salinity could develop gradually. If at all possible, avoid using water with high or moderate salt content for irrigation.

Fertilizers are salts. If fertilizers accumulate in the soil to excess levels, they can interfere with plant germination and growth just as natural soil salts do. Therefore, do not place high amounts of soluble, granular fertilizers with or near salt-sensitive portions of the crop such as the seeds or newly transplanted seedlings. Careful use

Table 5. Salt tolerance of vegetable crops from the late seedling stage until maturity

Sensitive (0-4 mS/cm)	Moderately sensitive (4-8 mS/cm)	Moderately tolerant (8-15 mS/cm)
Beans	Broccoli	Asparagus
Carrots	Brussels sprouts	Beets
Celery	Cabbages	Spinach
Eggplants	Cauliflower	
Onions	Cucumbers	
Peas	Lettuce	
	Peppers	
	Potatoes	
	Radishes	
	Tomatoes	

of fertilizers, in combination with regular soil testing, is important to avoid over-fertilization that can lead to soil salinity.

Another type of salinity problem occurs when soil sodium levels are high in relation to levels of calcium and magnesium. The sodium adsorption ratio (SAR) is the ratio of sodium to the beneficial soil structural cations, calcium and magnesium. When the SAR value exceeds 13, the soil is "sodic" (sodium-rich). Sodic soils are very sticky and slippery when wet and they are very hard, cloddy and prone to crusting when dry.

Soil organic matter

Soil organic matter is a general term applied to plant and animal tissue in various stages of decomposition in the soil. Crude plant materials such as roots, leaves, vines, stems and straw start to become organic matter when they begin to be decomposed by soil micro-organisms.

As organic matter decomposes, it performs many important functions in the soil that contribute to soil health and plant growth:

- It is a food source for the growth and reproduction of soil micro-organisms.
- It is a source of both macro and micronutrients for growing plants.
- Acids formed during the decomposition of organic matter release plant-available nutrients from soil minerals.
- Organic matter improves a soil's structure, aeration, water penetration and water-holding capacity through both physical and chemical action.

Organic matter levels are often given in soil test reports.

Rapid and extensive loss of soil organic matter can occur when only vegetable crops are grown in a field year after year. This practice can lead to soil compaction. Some pesticides cannot be used in soils that have less than 2 per cent organic matter. Every effort should be made to maintain or augment soil organic matter.

Plant tissue analysis

Plant tissue analysis measures the nutrient levels in the growing crop. Test values are compared with established values for inadequate, adequate and excess levels for each nutrient and plant species. In this way, the nutritional health of the crop can be assessed throughout the growing season, and the supply and availability of nutrients can be adjusted accordingly.

Tissue testing provides a fairly accurate read of what fuel is in the engine (plant), whereas soil testing provides information on what fuel is in the tank (soil).

Plant tissue analysis is useful in fine tuning a fertilizer management program (including a soil testing program), diagnosing nutrient-related crop production problems and identifying nutrient levels in crops that may be limiting yields.

Like soil testing, the validity and usefulness of plant tissue analysis depends on proper plant sampling and sample handling procedures:

- Sample crops from individual fields separately.
- Sample the proper plant part at the proper growth stage. This stage is specific to each individual crop and lab. Obtain sampling guidelines from a reliable laboratory providing the service (see the Appendix).
- Sample an adequate number of representative plants from a large number of typical locations in a field. Abnormal plants from non-representative field locations should not be included unless the comparative sampling approach is used. In this approach, samples are taken separately from both normal and abnormal areas to determine if plant nutrition is the cause of the apparent difference.
- Have tissue samples analyzed as soon as possible. To preserve them until testing, either refrigerate the samples at less than 10°C (50°F) or dry them at less than 35°C (95°F).
- Avoid contamination of samples with any foreign matter (e.g. fertilizer dust, cigarette ashes and other substances).

Managing soil fertility

Increasing soil organic matter

It is important to maintain and replenish the organic matter content of the soil used for vegetable production as this practice helps maintain good soil structure and soil quality. This approach is particularly important in soils that are typically low in organic matter, such as Brown or Dark Brown soils.

Organic matter can be maintained or increased through any combination of the following methods:

- growing vegetables in regular rotations with grain and hay crops
- incorporating crop residue
- applying animal manures
- growing and working in green manure crops
- applying biosolids (see Glossary)

On land repeatedly cropped to vegetables, the application of animal manure may be the most practical way to maintain soil organic matter.

Animal manures

Manures vary greatly in their organic matter and nutrient content. The type of animal (e.g. beef, poultry, etc.), type of feed, feeding method, volume and type of bedding, moisture content, age of the manure, method of storage and degree of rotting or drying can all affect the nutrient composition of a manure.

Table 6 lists approximate amounts of nitrogen, phosphorus and potassium in various types of animal manures.

While fresh manure contains significant amounts of nitrogen, much of this nitrogen is lost during storage by volatilization into the air or by leaching due to rain. The nitrogen content in old manure may be very low.

If plant material (grain, straw, etc.) treated with long lasting herbicides such as picloram or clopyralid is fed to livestock, the resulting manure can contain damaging levels of herbicide residues. Herbicide residues can also be introduced to the soil if using straw for bedding that has been sprayed with these same herbicides.

Table 6. Types of animal manure and approximate nutrient composition

Source	Average moisture (%)	Approximate composition (kg/tonne)			Approximate composition (lb./ton)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
Beef	50	10	8	5.5	20	16.1	11
Dairy	85	4.5	5	1.95	9	10	3.9
Swine (liquid)	96	3.5	2	2.5	7	4	5
Swine (solid)	50	8	2.8	3.45	16	5.6	6.9
Poultry (liquid)	90	6	2.4	5.75	12	4.8	11.5
Poultry (solid)	45	27	11	31.7	54	22	63.4
Sheep	50	10	12.6	4.9	20	25.2	9.8

Source: Adapted from 2000 Code of Practice for Responsible Livestock Development and Manure Management (Agdex 400/27-2), Alberta Agriculture and Rural Development. No longer in print.

When using manures in combination with commercial fertilizers, it is recommended that the amount of fertilizer nutrients applied be reduced by the amount of nutrients contributed by the manure. Testing the manure can give a good indication of its expected nutrient contribution. Remember that not all the nutrients in manure are immediately available within a cropping season. Monitor the soil's nutrient content by soil testing, to avoid overloading the soil.

Fresh manure contains salts, so consider the salt levels in both the manure and the soil when making application decisions. Additionally, fresh manure may contain large numbers of viable weed seeds that can infest clean land, or it may contain pathogens (e.g. *E. coli*).

Composted manure is usually suitable for spreading after it has been composted for 1 or 2 years. The composting process is more complex than simply allowing manure to sit in a pile. It involves turning and mixing the manure to aerate the pile and evenly distribute materials and moisture as well as to allow temperatures to reach a critical level. This process encourages a rapid rate of microbial decomposition, stabilizing organic matter and nutrient content, reducing manure volume and killing off weed seeds and pathogens.

Composted manure should be applied in the fall and worked into the soil immediately. This practice allows adequate mixing and breakdown of the manure before spring seeding and minimizes the loss of nitrogen from the manure into the air. Do not apply fresh manure directly to growing crops due to the potentially high risk for contamination of the crop by organisms in the manure (e.g. pathogens).

Do not apply manure in the same year that potatoes or rutabagas are to be grown. Potatoes may become rough with scab and rutabagas uneven and cracked in heavily manured land.

Green manures

Green manures can be planted in the late summer to early fall and left to overwinter as a cover crop to prevent soil erosion and to collect snow. Spring wheat and oats seeded at about 112 kilograms (kg) per hectare (ha) (100 pounds (lb.) per acre (ac.)) can be used for cover crops. A mixture of peas at 69 kg/ha (62 lb./ac.) and oats at 112 kg/ha (100 lb./ac.) or straight oats are good green manure crops that can be planted and ploughed down the same year.

Green manure crops should be provided with some fertilizer. Some of the nitrogen and most of the phosphorus will be available for the following vegetable crop. If a green manure crop is left over the winter, broadcast the fertilizer for the vegetable crop after ploughing down the green manure crop, but before the shallow cultivation used to prepare the seedbed for the vegetable crop. Some additional nitrogen fertilizer may be required to replace that used in the decomposition of the green manure crop.

Commercial synthetic fertilizers

The use of synthetic, inorganic fertilizers is a common practice in modern agriculture and is especially important in vegetable crops because these crops tend to have very high and specific fertility requirements. The use of specifically blended synthetic fertilizers allows producers to accurately supply a precise quantity of plant-available nutrients to their vegetable crops. This ability can increase efficiency and crop productivity while taking out some of the guesswork associated with nutrient supply and availability from organic fertilizer sources such as manure.

Fertilizers are labelled according to the guaranteed analysis expressed as the percentage by weight of each nutrient element contained in the fertilizer.

The main nutrient elements in the synthetic fertilizers commonly employed on the Canadian Prairies:

- nitrogen (N)
- phosphorus (as phosphate, P_2O_5)
- potassium (as potash, K_2O)
- sometimes sulphur (S)

For example, a 45-kg (100-lb.) bag of 11-48-0 fertilizer contains 5 kg (11 lb.) of nitrogen (N), 22 kg (48 lb.) of phosphorus (as P_2O_5) and 0 kg (0 lb.) of potassium. Fertilizers that contain sulphur would have the per cent sulphur expressed as a fourth number. Micronutrients (zinc, boron, etc.) may be provided in trace amounts, which will also be indicated on the bag.

Fertilizer should be purchased on the basis of the price per kilogram (pound) of nutrient as well as the suitability for use with the particular crop and cropping system, in terms of crop safety and nutrient availability over time. Some types of fertilizer formulations are not appropriate for use in certain applications. Consider discussing the efficacy and suitability of the various options with your fertilizer supplier.

Synthetic fertilizers may be broadcast, banded, drilled, applied through the irrigation system (fertigation) or sprayed as a foliar application. The method used depends on the nutrient element, fertilizer formulation and crop requirement (see the section later in this chapter on Fertilizer Application Methods). Ensure that any application is done after careful calculation of rates and calibration of equipment and that the application method minimizes fertilizer losses or waste.

Nitrogen fertilizer

Because nitrogen (N) moves readily in moist soil, it does not have to be applied near the seed. Excess N drilled with the seed can reduce germination and seedling emergence. It may not be desirable to place any N fertilizer near the seed due to the potential for salt damage to the young seedlings. However, surface application or shallow incorporation of N fertilizers can result in reduced uptake if the seedbed remains dry during the early growing season.

Nitrogen fertilizers can be applied in spring or late fall. Nitrogen applied in the fall has a greater opportunity to move deeper into the root zone. Wet conditions that may occur in some areas of the Prairies on fine-textured and poorly drained soils can cause significant losses of applied N because of denitrification (loss of gaseous N). Therefore, fall application is not recommended on poorly drained areas where the soil remains saturated or flooded for an extended period in the spring. If possible, delay fall N application until the soil temperature drops to 0°C (32°F) or lower.

For largely shallow-rooted vegetable crops, focus on supplying the N requirements to the crop so as to reduce losses and to ensure that the nutrients are available when and where they are needed.

Table 7 outlines key characteristics of common nitrogen fertilizer sources.

Table 7. Nitrogen fertilizer sources		
Common name	**Analysis**	**Comments**
Ammonium nitrate	34-0-0	• contains nitrogen in both the ammonium and nitrate forms • can be applied to foliage at low concentrations with minimal leaf scorching • subject to leaching losses on sandy soils • blended with ammonium phosphate to make the common fertilizer grades 23-23-0 and 26-13-0 • may be difficult to access due to security issues (can be used to make explosives)
Ammonium sulphate	21-0-0-24S	• used when significant amounts of supplemental sulphur are required • blended with ammonium phosphate to make 16-20-0 • more acidifying than other nitrogen fertilizers and should not be used continuously on acid soils
Urea	46-0-0	• highest analysis dry nitrogen fertilizer • used for direct application or combined with phosphate to make 27-27-0 • subject to loss by volatilization if not incorporated into the soil • significant losses can occur when applied under warm, dry conditions to sandy soils and on alkaline soils (pH 7.5 or higher)
Anhydrous ammonia	82-0-0	• highest analysis nitrogen fertilizer • suitable for fall or spring application for annual crops • a narrow shank applicator with 40-cm (16-in.) spacing is commonly used to inject ammonia at a depth of 10-15 cm (4-6 in.) – the soil must be worked behind the application shank to prevent escape of the ammonia gas • CAUTION: anhydrous ammonia is a pressurized gas
Urea - ammonium sulphate	34-0-0-11S	• contains 11% sulphur • supplies adequate sulphur when used as the nitrogen source on sulphur-deficient soils
Urea - ammonium nitrate solutions	28-0-0 & 32-0-0	• losses due to volatilization and immobilization may occur if these liquid formulations are sprayed on heavy trash (crop debris) cover • solutions lend themselves to uniform application and ease of handling • used in fertigation
Urea - ammonium sulphate solution	20-0-0-5S	• contains 5% sulphur • may supply adequate sulphur when used as the nitrogen source on sulphur-deficient soils • losses due to volatilization and immobilization may occur if sprayed on heavy trash (crop debris) cover • solutions lend themselves to uniform application and ease of handling

Nitrogen is used to build amino acids; it is critical for the formation of chlorophyll, and it is essential for healthy plant growth, good yields and productive plants. Nitrogen is often associated with vegetative growth, but it is also important in ensuring good quality fruit growth.

Nitrogen is required at all crop stages and moves within the plant to ensure that new tissues are adequately supplied. Deficient plants may be stunted, yellowed and weak. Over-application of nitrogen leads to lush, soft growth and may result in toxicity.

Phosphorus fertilizer

Phosphorus (P) does not move readily in soil, so P fertilizers must be placed near the roots to be most effective. For all vegetable crops, fertilizers should not be placed directly with the seed, as damage will occur.

On perennial crops like asparagus, a greater response may occur in the years following application of the P fertilizer than in the year of application. On soil very deficient in phosphorus, phosphate fertilizer should be applied and incorporated before seeding perennial crops.

Most crops will respond to properly applied phosphate fertilizer when the available soil phosphorus level is low. The high pH calcareous soils found in various areas of the Prairies tend to "fix" or reduce the availability of applied P and slow the buildup of soil test levels.

Repeated applications of the relatively high rates of phosphate fertilizer recommended for vegetable crops will gradually increase the available P content of most soils. Eventually, little additional P fertility will be required. This situation is especially true if manure is used as the N source; in fact, there is the potential for P overloading to occur.

Vegetable seedlings require abundant P to achieve maximum growth. Placing P fertilizer where developing roots can access it rapidly is critical in attaining these high phosphorus levels in young plants.

Deep banding phosphate at a depth of 10 to 15 cm (4 to 6 in.) and at spacings of 30 cm (12 in.) or less before seeding or mid-row banding during seeding is more effective in increasing yields than broadcast and incorporation methods. Such side-banded applications are recommended for most oilseeds, annual legumes and row crops.

The application of 11 to 17 kg P_2O_5/ha (10 to 15 lb. P_2O_5/ac.) near the seed may also be required to ensure adequate P supplies for early growth before roots can grow into the fertilizer bands. Such applications may be especially beneficial when soils are cold and/or very deficient in phosphorus or when the phosphate is dual banded with a high rate of urea nitrogen in spring.

Although P fertilizers have less potential to cause salt burn to seedlings than the N fertilizer sources, it is important to be very careful with vegetable crops. If P is being applied, monoammonium phosphate (11-52-0) is recommended because it has a low salt index and does not produce much ammonia, so it has relatively low toxicity to seedlings (Table 8).

Table 8. Phosphorus fertilizer sources

Common name	Analysis	Comments
Monoammonium phosphate (MAP)	11-48-0, 11-51-0, 11-52-0, 11-54-0 & 11-55-0	• the most commonly available phosphorus fertilizer • used for banded or broadcast application • blended with nitrogen fertilizers to give various nitrogen phosphate fertilizers such as 16-20-0, 23-23-0, 27-27-0 and 26-13-0

Phosphorus is not prone to leaching but can move with drifting soil. Losses of P into surface water will decrease water quality. Best management practices (BMPs) to manage P include the following:

- regular soil testing
- appropriate fertilizer applications (rates, timing, placement and formulation)
- soil conservation practices such as conservation tillage, forages and buffer strips to prevent P pollution due to soil erosion

Phosphorus is a critical nutrient in that it plays a role in energy transfer processes in plants. It is also important in cellular growth, and P deficiencies are often expressed as poor leaf growth or reduced numbers of leaves as well as poor fruit quality. Phosphorus moves readily within the plant.

Potassium fertilizer
Where required, applying potassium fertilizers (K) can increase crop yield and quality. Depending on the type of crop, enhancing the K fertility levels may also increase frost and disease resistance, palatability, storage quality and other characteristics.

Potassium will move in the soil more readily than phosphorus, but K fertilizers are still most efficiently utilized when drilled with or near the seed. For small-seeded vegetable crops, the maximum safe rate for K applied with the seed is 20 kg/ha (18 lb./ac.).

Alternatively, K fertilizer can be broadcast and then incorporated into the soil, with applications in either fall or spring. However, the efficiency of broadcast and incorporated potash (KCl) is about 50 per cent of potash banded with the seed or side-banded. Therefore, adjust K rates based on application method to obtain equal crop response.

Table 9 lists characteristics of common potassium fertilizers.

Potassium is important in the formation of enzymes. It also plays a role in stomatal closure and, therefore, can be important in water absorption and associated stress. Potassium is important in increasing root growth, maintaining turgor (rigidity of cells), ensuring effective photosynthesis and maintaining good crop quality (pre- and post-harvest).

Sulphur fertilizer
Sulphate forms of sulphur (S) fertilizer, primarily ammonium sulphate and liquid ammonium thiosulphate, are equally effective when surface-applied, banded or incorporated.

Elemental S must be oxidized by soil micro-organisms to form sulphate before plants can use it. For that reason, elemental S should be applied at least a year before it is needed by the crop and then left on the surface as long as possible before incorporation. Rainfall and weathering will help disperse the fertilizer granules and speed the conversion to the sulphate form.

Sulphur is important in the formation of proteins and catalyzing photosynthetic processes.

Micronutrient fertilizers
As noted earlier, micronutrients are essential to the healthy and productive growth of plants, but are required in only very small quantities. They include calcium, magnesium, manganese, boron,

Table 9. Potassium fertilizer sources

Common name	Analysis	Comments
Muriate of potash	0-0-60 or 0-0-62	• most commonly available potassium fertilizer • used directly as a broadcast application or mixed with phosphate and nitrogen fertilizers to make fertilizer grades such as 10-30-10, 8-24-24, 13-13-13, etc.

Note: The cost of potash in some of the complete fertilizers tends to be considerably higher than in 0-0-60 or 0-0-62. Prices should be compared on the basis of cost per kilogram (pound) of nutrient.

zinc, molybdenum, copper, iron, chlorine and nickel. Sulphur is considered a micronutrient for some crops. Calcium and magnesium are typically required in higher amounts than the other micronutrients.

Micronutrients vary in their availability in soil depending on soil pH and other factors. Micronutrient requirements also vary depending on the crop. In most Prairie soils, supplies of most micronutrients are sufficient to meet the needs of most vegetable crops. The addition of a specific micronutrient may be required in some situations. Micronutrients may be applied as a targeted foliar application or as a part of a fertilizer blend.

Be careful when applying micronutrients because there is a fine line between insufficient and toxic levels.

Fertilizer application methods

Methods commonly used to apply fertilizer to vegetable crops:

- broadcasting
- top-dressing
- banding
- side-dressing
- drilling
- fertigation

Broadcasting

Broadcasting refers to spreading a granular fertilizer on a soil surface before a crop has been seeded. Incorporation of the fertilizer into the soil follows broadcasting, usually as part of seedbed preparation. Broadcasting is usually done in the spring, but it can be done in the fall.

Broadcasting is not an efficient method when crop rows are spaced far apart and plant roots do not meet between rows. Fertilizer rates must typically be increased for broadcast applications due to the inherent inefficiency. See the previous sections on phosphorus and potassium fertilizers for the limitations of broadcast applications.

Top-dressing

Top-dressing is the spreading of a granular fertilizer on a field while the crop is growing. The fertilizer is not incorporated, but the crop may be irrigated to wash the granules off the leaves and into the soil profile.

Normally, top-dressing is restricted to nitrogen fertilizers, as N moves readily through the soil profile. Top-dressing is used to augment or supplement the N fertilizers applied at planting. It is a tool to respond to mid-season N shortfalls that may have been diagnosed by tissue testing.

Banding

Banding refers to the precise placement of fertilizer in a band within reach of the developing root system. The bands of fertilizer are applied below and/or to the side of the seed row. Banding is a particularly efficient method of applying phosphorus fertilizer. Banding may also be used to apply supplemental nitrogen.

Side-dressing

Side-dressing is the banding of fertilizers in the soil to the side of the crop row after plants are established. It is similar to top-dressing in that it allows producers to supplement the N fertilizer applied at planting. As the fertilizers are placed close to the plants in the soil, there is a reduced risk of volatile losses compared to top-dressing. Care should be taken to not damage crop roots.

Drilling

Drilling is the application of fertilizer near the seed in the same drill row or furrow. Applicators should be set so that as little fertilizer as possible is placed directly with the seed. Some mixing of seed, fertilizer and soil should occur. Phosphorus fertilizers are commonly applied to large-seeded vegetable crops by drilling.

Fertigation

Fertigation involves the application of soluble fertilizer in irrigation water. The fertilizer solution is added to the irrigation water using a metering injector pump or by feeding the fertilizer solution into the pump intake line by suction or gravity.

Fertigation is typically used to supply small quantities of nutrients regularly throughout the growing season. When applied using a sprinkler-type irrigation system, fertigation is similar to a broadcast application of fertilizer. Applying the fertilizer solution through a drip irrigation system is more precise and efficient.

Advantages of fertigation:

- the ability to closely control fertilizer amounts applied (small amounts are applied as needed, for immediate use)
- the ability to apply nutrients at any time according to crop needs
- no mechanical damage to the crop during application
- prevention of soil compaction by the equipment required to spread dry granular products
- uniform nutrient application when irrigation water is applied uniformly

Disadvantages of fertigation:

- higher cost of fertilizer
- potentially higher cost of application due to specialized equipment for precision application (e.g. drip irrigation infrastructure)
- potential for fertilizer solutions to corrode the irrigation equipment if the systems are not flushed after use
- lack of uniform nutrient application if irrigation water is not applied uniformly

Other soil amendments

The purpose of soil amendments is to improve soil health and soil quality. Amendments may be added in an effort to improve soil drainage and aeration, improve soil texture, change soil pH or alter the ability of plants to access different nutrients.

Amendments might include inorganic materials like gypsum, lime or perhaps water with acids added. Organic amendments might include organic matter or micro-organisms, such as bacterial inoculants.

Many amendments are available for producers to purchase and use. The value of each product is debatable. When it comes to soil improvement, there really are no “magic bullets” for any soil. Use care and caution when considering a new product (“buyer beware”).

Seedbed preparation and seed germination

Soil is the base upon which the crop is grown. Without proper preparation and excellent soil conditions, seeds will not germinate quickly and evenly, and subsequent crop growth, yields and quality will be negatively affected.

Depending on the state of the field, a number of preparatory activities may be required prior to planting. These activities may involve breaking, disking, cultivating and/or rototilling/rotovating.

Shortcuts or rushing field preparation will almost inevitably result in problems later in the season. During seedbed preparation, consider factors such as soil crusting, soil temperature and soil moisture, which all influence the speed and uniformity of seed germination and emergence.

Seedbed preparation

A good seedbed must be level and have uniform compaction and adequate, evenly distributed moisture. The best way to obtain a homogeneous seedbed is to postpone preparing the soil until it has dried out enough so that it can be treated uniformly, even in the wettest areas.

Proper depth of cultivation is important for optimum germination. It is critical to ensure excellent contact between the seed and the soil, as this contact will directly affect germination. A light, fluffy seedbed may look nice, but if it results in poor seed-to-soil contact, there will be problems with seed germination.

Mounting a packer or roller behind the rotovator or in front of the seeder will compact the soil enough to improve seed-to-soil contact. The small packer wheels on seeder units generally do not provide adequate compaction. Alternatively,

Shaped bed prior to plastic mulch application and transplanting
Photo: Robert Spencer

conducting an independent packing or rolling operation before planting may also be effective.

The use of raised beds can be beneficial in creating an excellent seedbed of proper depth for most crops, with good drainage, moisture distribution and temperature. Raised beds may be created using a range of machinery and can be combined with other technologies, such as plastic mulch.

Soil crusting

The single most important cause of poor emergence is the tendency of soil particles to stick together to form a crust on the soil surface. This crusting can occur in all types of soil and in both wet and dry conditions.

As the diameter of soil particles gets smaller (i.e. clays), particles stick together more, crusting increases, soil density increases, aeration decreases, and other adverse effects multiply. Typically, the amount of cohesion (particles sticking together) increases with time after cultivation.

Getting a good crop stand, therefore, becomes a race between germination and emergence and the development of a soil crust. The speeds of seed germination and soil crusting are affected by the same three factors: moisture, aeration and temperature.

Soil temperature

Seed germination depends, in part, on soil temperature. Each crop has an optimum temperature range for maximum germination rate (Table 10). Below that optimum range, the lower the soil temperature, the slower the rate of germination will be. Also, when the soil is too cold to permit germination, seed decay organisms combined with soil crusting may hinder seedling emergence and reduce the plant stand.

Table 10. Soil temperature ranges for germination of various vegetable crops							
Crop	Minimum temperature		Optimum temperature		Maximum temperature		Germination rate (days)
	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	
Asparagus	10	50	15 - 29	59 - 84	35	95	–
Beans	15	59	15 - 29	59 - 84	35	95	7
Beets	4.4	40	10 - 29	50 - 84	35	95	7 - 10
Carrots, parsnips	4.4	40	7 - 29	45 - 84	35	95	12 - 15
Cole crops (broccoli cabbages, cauliflower)	4.4	40	7 - 29	45 - 84	38	100	5 - 10
Corn (sweet)	10	50	15 - 35	59 - 95	40	104	7 - 10
Cucurbits (cucumbers, melons, pumpkins, squash)	15	59	15 - 35	59 - 95	38	100	7 - 10
Eggplants, peppers	15	59	24 - 32	75 - 90	35	95	10
Lettuce	1.6	35	4.4 - 27	40 - 81	29	84	7 - 10
Onions	1.6	35	10 - 35	50 - 95	35	95	10 - 14
Peas	4.4	40	4 - 24	40 - 75	29	84	7 - 14
Rutabagas	4.4	40	15 - 40	59 - 104	40	104	5 - 10
Spinach	1.6	35	7 - 24	45 - 75	29	84	7 - 14
Swiss chard	4.4	40	10 - 29	50 - 84	35	95	7 - 14
Tomatoes	10	50	15 - 29	59 - 84	35	95	7 - 14

Soil moisture

When sold, seeds have normally been dried to a water content of only 5 to 6 per cent. Before they can germinate, seeds need to absorb sufficient moisture to bring their water content to 45 to 60 per cent.

If possible, seeding should not take place until seedbed moisture has had a chance to become more uniform by capillary action. This period may take around 5 to 8 days from the time of seedbed preparation.

The key to successful seed germination is to keep the top 1 cm (±0.5 in.) of soil moist. Too often, neglect at this early stage of production jeopardizes yield and quality of the entire crop.

If the seedbed moisture content is less than ideal, irrigation may be used to enhance germination. An irrigation system that can apply light applications of water frequently is preferred, as the system only needs to wet the top 2 cm (1 in.) of soil. Nozzles that emit fine water droplets are recommended because they reduce crusting and washouts that can be associated with large droplets. The different types of irrigation systems vary in their water application capabilities and flexibility (for more information, see the Irrigation Systems section later in this chapter).

A final note on seed and moisture relates to coated seed (see Pelleted Seed in the next section). Coated vegetable seed typically requires more moisture and time to germinate than does raw seed. It is critical to ensure that uniform levels of soil moisture are maintained when using coated seed.

Establishing a desired plant stand

For vegetables to achieve their maximum yield and quality potential, they must have adequate space and access to sufficient nutrients, light, moisture, etc. A uniformly spaced and evenly maturing plant stand makes efficient use of the field by minimizing both empty spaces and overcrowding.

Aside from making sure that seeds germinate and emerge uniformly, many other factors play a role in achieving a uniform and even plant stand and maximizing production.

Success in seeding

To achieve success with seeding, factors such as seed size, seed coating, per cent germination, seedbed preparation and seeding depth must be optimized.

Seed size and shape

Each vegetable crop differs in seed size and seed shape. You will need to adjust seed handling equipment, seeding amounts and other seeding practices accordingly.

Consider seed size and shape, in combination with seed quality factors such as seed lot germination and field conditions, when calculating the

A variety of vegetable seeds and seed treatments
Photo: Jackie Bantle

amount of seed required to achieve a specific plant population and in setting the seeding depth. Additional factors, such as whether seeds are coated, pre-graded/sized, etc., may factor into the calculations. (See Tables 11A and 11B for seed amounts, spacings and depths.)

Graded or sized seed
Grading seed for size uniformity improves seeder performance while also producing more consistent rates of emergence. When using belt seeders, the seed lot should be sized such that the largest seeds pass easily through the holes in the belt, while no more than two of the smallest seeds can pass side-by-side through the same hole.

Small quantities of seed can be graded at home or in the shop by using a series of sieves. Seed of cole crops (broccoli, brussels sprouts, cauliflower, cabbages), radishes, beans, onions, rutabagas and turnips have been successfully sized using simple sieve systems. Onion and carrot seeds present more of a problem because of their irregular shape.

Pelleted seed

The practice of coating seed, called seed pelleting, was developed to improve the ease of handling and planting of small, irregularly shaped vegetable seed. In the process of seed pelleting, the surface of the seed is covered with an inert material, such as clay, diatomaceous earth, polymers, sand or some other material. A number of materials are often used in combination to ensure the seed coating allows sufficient oxygen and water to reach the seed after planting.

Pelleted seed is available from many but not all seed companies. It costs more than raw seed. Coatings vary in formulation and in the volume applied to seeds. Most pelleted seed in an individual lot is fairly uniform in size and can be used as recommended. However, occasionally a few larger pellets are formed, and these can be a nuisance when seeding. A minimum rather than a maximum thickness of coating is recommended.

Pelleted seed must have a high germinating capability. Seeds with a low germination percentage defeat the purpose of precision seeding and should not be pelleted.

For all types of pelleted seed, be sure the soil is irrigated with frequent, light water applications for better germination. Pelleted seed can require more moisture and time to germinate than raw seed. Therefore, greater care may be required for a longer period to ensure maximum germination.

Seed priming

Seed priming is done to increase the speed, uniformity and overall percentage of seed germination. Seed priming involves soaking the seed prior to planting. Soaking starts the germination process, but the seed is planted before germination is completed. Seeds that have been primed may be then dried down and stored for a period of time, or they may be planted soon after priming.

Extreme care must be taken to ensure that seeds are not "over-primed," or progress too far into germination, as these seeds may be damaged or perform poorly when placed in the soil. Primed seed may also have a shorter shelf life than regular, non-primed seed.

The number of very specific requirements (temperature, moisture level, duration) involved in seed priming make it a very complex and potentially very risky option. Seed priming is not a very common practice.

Seed amount, placing and depth

Tables 11A and 11B list required seed amounts for crops seeded directly into the field and for those started in the greenhouse as transplants. These tables also detail desired final plant spacings and planting depths. Tables 12A and 12B list the number of plants both per hectare and per acre when using different plant spacings.

Table 11A. Seed amount, spacing and depth requirements for vegetable crops (metric measures)

Vegetable	Approx.* seeds per gram	Seed required			Desired final plant spacing		Depth of planting (cm)
		For 30-m row seeded direct (g)	(per ha) Trans - planted (kg)	(per ha) Seeded direct (kg)	Apart in row (cm)	Between rows (cm)	
Asparagus	25 - 53	28	2.27	6.81	30	90 - 120	2.5 - 3.75 in furrows
Beans (bush)	2 - 4.5	454	-	51 - 91	2.5 - 5	60 - 90	3.75 - 5
Beets	53 - 57	28	-	11 - 18	2.5 - 5	30 - 60	1.25 - 2.5
Broccoli	317	7	0.284	0.57 - 2.27	30 - 45	45 - 75	0.625 - 1.88
Brussels sprouts	282 - 317	7	0.284	-	45 - 60	45 - 90	0.625
Cabbages	282 - 317	7	0.284	0.57 - 2.27	25 - 50	60 - 90	0.625 - 1.25
Cabbages, Chinese	317	7	0.284	0.57 - 2.27			0.625 - 1.25
Carrots	423 - 888	14	-	3.4 - 5.7	2.5	45 - 60	0.625 - 1.25
Cauliflower	282 - 317	7	0.284	0.57 - 2.27	30 - 45	60 - 90	0.625 - 1.25
Celery	1,761 - 2,465	7	0.284 - 0.568	-	15 - 20	45 - 90	0.31 - 0.625
Corn (sweet) *(su, se)*	4 - 6	114	-	11 - 17	15 - 35	55 - 90	2.5 - 5
Corn (sweet) *(sh2)*	6 - 11	85 - 114	-	13.6 - 17	20 - 30	75 - 105	2.5 - 5
Cucumbers	33 - 35	14	1.1 - 2.27	3.4 - 5.7	7.5 - 15	120 - 180	1.25 - 5
Eggplants	211 - 229	4	0.284	-	45 - 60	60 - 90	0.625 - 1.25
Lettuce (head)	704 - 880	14	0.568	1.1 - 2.27	20 - 36	30 - 60	0.625 - 1.25
Lettuce (leaf)	880 - 1,056	14	0.568	1.1 - 3.4	20 - 30	30 - 60	0.625 - 1.25
Onions (dry bulb)	282 - 335	28	-	3.4 - 4.5	5 - 10	30 - 60	0.625 - 1.25
Onions (bunching)	396 - 440	28	-	3.4 - 4.5	-	-	1.25 - 1.88
Parsnips	211 - 423	14	-	3.4	2.5 - 7.5	45 - 60	0.625 - 1.25
Peas	4 - 9	454	-	57 - 341	2.5 - 7.5	15 - 60	2.5 - 5
Peppers	141 - 162	4	0.284	-	30 - 45	45 - 75	0.625
Pumpkins	4	14	1.1 - 2.27	3.4 - 4.5	90 - 120	240 - 360	2.5 - 5
Radishes	70	28	-	11 - 17	2.5	20 - 30	0.625 - 1.25
Rutabagas	282 - 423	14	-	0.57 - 2.27	10 - 15	60	0.625 - 1.25
Spinach	99	28	-	17	5 - 10	30 - 45	1.25 - 2.5
Squash (summer)	7 - 10	14	1.1 - 2.27	1.1 - 3.4	90 - 120	90 - 240	2.5 - 5
Squash (winter)	4 - 9	7 - 14	1.1	2.27 - 4.5	90 - 240	180 - 240	2.5 - 5
Swiss chard	55	28	-	6.8 - 9.1	30 - 38	60 - 90	1.25
Tomatoes	352 - 387	4	0.142	-	45 - 60	60 - 90	0.625

* The number of seeds per gram may vary considerably.

Table 11B. Seed amount, spacing and depth requirements for vegetable crops (imperial measures)

Vegetable	Approx.* seeds per ounce	Seed required			Desired final plant spacing		Depth of planting (in.)
		For 100-ft. row seeded direct (oz.)	(per ac.) Trans-planted	(per ac.) Seeded direct (lb.)	Apart in row (in. or ft.)**	Between rows (in. or ft.)**	
Asparagus	700 - 1,500	1	2 lb.	6	12 in.	36 - 48 in.	1 - 1.5 in furrows
Beans (bush)	60 - 125	16	- -	45 - 80	1 - 2 in.	24 - 36 in.	1.5 - 2
Beets	1,500 - 1,625	1	- -	10 - 16	1 - 2 in.	12 - 24 in.	0.5 - 1
Broccoli	9,000	¼	4 oz.	½ - 2	12 - 18 in.	18 - 30 in.	0.25 – 0.75
Brussels sprouts	8,000 - 9,000	¼	4 oz.	-	18 - 24 in.	18 - 36 in.	0.25
Cabbages	8,000 - 9,000	¼	4 oz.	½ - 2	10 - 20 in.	24 - 36 in.	0.25 - 0.5
Cabbages, Chinese	9,000	¼	4 oz.	1 - 2	10 - 18 in.	18 - 36 in.	0.25 - 0.5
Carrots	12,000 - 25,000	½	- -	3 - 5	1 in.	18 - 24 in.	0.25 - 0.5
Cauliflower	8,000 - 9,000	¼	4 oz.	½ - 2	12 - 18 in.	24 - 36 in.	0.25 - 0.5
Celery	50,000 - 70,000	¼	4 - 8 oz.	-	6 - 8 in.	18 - 36 in.	0.125 - 0.25
Corn (sweet) *(su, se)*	100 - 160	4	- -	10 - 15	6 - 14 in.	22 - 36 in.	1 - 2
Corn (sweet) *(sh2)*	180 - 310	3 - 4	- -	12 - 15	8 - 12 in.	30 - 42 in.	1 - 2
Cucumbers	930 - 1,000	½	1 - 2 lb.	3 - 5	3 - 6 in.	4 - 6 ft.	0.5 - 2
Eggplants	6,000 - 6,500	1/8	4 oz.	-	18 - 24 in.	24 - 36 in.	0.25 - 0.5
Lettuce (head)	20,000 - 25,000	½	8 oz.	1 - 2	10 - 14 in.	16 - 24 in.	0.25 - 0.5
Lettuce (leaf)	25,000 - 30,000	½	8 oz.	1 - 3	8 - 12 in.	12 - 24 in.	0.25 - 0.5
Onions (dry bulb)	8,000 - 9,500	1	- -	3 - 4	2 - 4 in.	12 - 24 in.	0.25 - 0.5
Onions (bunching)	11,250 - 12,500	1	- -	3 - 4	-	-	0.5 - 0.75

Continued

Table 11B. Seed amount, spacing and depth requirements for vegetable crops (imperial measures)

Vegetable	Approx.* seeds per ounce	Seed required				Desired final plant spacing				Depth of planting (in.)
		For 100-ft. row seeded direct (oz.)	(per ac.)			Apart in row (in. or ft.)**		Between rows (in. or ft.)**		
			Trans-planted		Seeded direct (lb.)					
Parsnips	6,000 - 12,000	½	-	-	3	1 - 3	in.	18 - 24	in.	0.25 - 0.5
Peas	100 - 250	16	-	-	50 - 300	1 - 3	in.	6 - 24	in.	1 - 2
Peppers	4,000 - 4,600	1/8	4	oz.	-	12 - 18	in.	18 - 30	in.	0.25
Pumpkins	100 - 250	½	1 - 2	lb.	3 - 4	3 - 4	ft.	8 - 12	ft.	1 - 2
Radishes	2,000 - 3,500	1	-	-	10 - 15	1	in.	8 - 12	in.	0.25 - 0.5
Rutabagas	8,000 - 12,000	½	-	-	½ - 2	4 - 6	in.	24	in.	0.25 - 0.5
Spinach	2,800	1	-	-	15	2 - 4	in.	12 - 18	in.	0.5 - 1
Squash (summer)	200 - 280	½	1 - 2	lb.	4 - 6	3 - 4	ft.	3 - 8	ft.	1 - 2
Squash (winter)	100 - 250	¼ - ½	1	lb.	2 - 4	3 - 8	ft.	6 - 8	ft.	1 - 2
Swiss chard	1,560	1	-	-	6 - 8	12 - 15	in.	24 - 36	in.	0.5
Tomatoes	10,000 - 11,000	1/8	2	oz.	-	18 - 24	in.	24 - 36	in.	0.25

* The number of seeds per ounce may vary considerably.
** Imperial measures in this column are given in both feet and inches to ease understanding.

Table 12A. Number of plants per hectare at various plant spacings (metric measures)									
Distance between plants within row (cm)	**Distance between rows (cm)**								
	30	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**
2.5	1,333,333	888,889	666,667	533,333	444,444	380,952	333,333	296,296	266,667
5	666,667	444,444	333,333	266,667	222,222	190,476	166,667	148,148	133,333
7.5	444,444	296,296	222,222	177,778	148,148	126,984	111,111	98,765	88,889
10	333,333	222,222	166,667	133,333	111,111	95,238	83,333	74,074	66,667
20	166,667	111,111	83,333	66,667	55,556	47,619	41,667	37,037	33,333
25	133,333	88,889	66,667	53,333	44,444	38,095	33,333	29,630	26,667
30	111,111	74,074	55,556	44,444	37,037	31,746	27,778	24,691	22,222
35	95,238	63,492	47,619	38,095	31,746	27,211	23,810	21,164	19,048
40	83,333	55,556	41,667	33,333	27,778	23,810	20,833	18,519	16,667
45	74,074	49,383	37,037	29,630	24,691	21,164	18,519	16,461	14,815
50	66,667	44,444	33,333	26,667	22,222	19,048	16,667	14,815	13,333
55	60,606	40,404	30,303	24,242	20,202	17,316	15,152	13,468	12,121
60	55,556	37,037	27,778	22,222	18,519	15,873	13,889	12,346	11,111
65	51,282	34,188	25,641	20,513	17,094	14,652	12,821	11,396	10,256
70	47,619	31,746	23,810	19,048	15,873	13,605	11,905	10,582	9,524
75	44,444	29,630	22,222	17,778	14,815	12,698	11,111	9,877	8,889
80	41,667	27,778	20,833	16,667	13,889	11,905	10,417	9,259	8,333
85	39,216	26,144	19,608	15,686	13,072	11,204	9,804	8,715	7,843
90	37,037	24,691	18,519	14,815	12,346	10,582	9,259	8,230	7,407
120	27,778	18,519	13,889	11,111	9,259	7,937	6,944	6,173	5,556
metres of row per hectare	33,333	22,222	16,667	13,333	11,111	9,524	8,333	7,407	6,667

The equation for calculating the number of plants per hectare is:

$$\text{Number of plants per hectare} = \frac{10{,}000\ m^2}{\text{Between-row spacing (m) X in-row spacing (m)}}$$

Note: To apply the equation, convert cm to m (#cm/100).

Table 12B. Number of plants per acre at various plant spacings (imperial measures)

Distance between plants within row (in.)	Distance between rows (in.)								
	12	18	24	30	36	42	48	54	60
1	522,720	348,480	261,360	209,088	174,240	149,349	130,680	116,160	104,544
2	261,360	174,240	130,680	104,544	87,120	74,674	65,340	58,080	52,272
3	174,240	116,160	87,120	69,696	58,080	49,783	43,560	38,720	34,848
4	130,680	87,120	65,340	52,272	43,560	37,337	32,670	29,040	26,136
5	104,544	69,696	52,272	41,818	34,848	29,870	26,136	23,232	20,909
6	87,120	58,080	43,560	34,848	29,040	24,891	21,780	19,360	17,424
8	65,340	43,560	32,670	26,136	21,780	18,669	16,335	14,520	13,068
10	52,272	34,848	26,136	20,909	17,424	14,935	13,068	11,616	10,454
12	43,560	29,040	21,780	17,424	14,520	12,446	10,890	9,680	8,712
14	37,337	24,891	18,669	14,935	12,446	10,668	9,334	8,297	7,467
16	32,670	21,780	16,335	13,068	10,890	9,334	8,168	7,260	6,534
18	29,040	19,360	14,520	11,616	9,680	8,297	7,260	6,453	5,808
20	26,136	17,424	13,068	10,454	8,712	7,467	6,534	5,808	5,227
22	23,760	15,840	11,880	9,504	7,920	6,789	5,940	5,280	4,752
24	21,780	14,520	10,890	8,712	7,260	6,223	5,445	4,840	4,356
26	20,105	13,403	10,052	8,042	6,702	5,744	5,026	4,468	4,021
28	18,669	12,446	9,334	7,467	6,223	5,334	4,667	4,149	3,734
30	17,424	11,616	8,712	6,970	5,808	4,978	4,356	3,872	3,485
32	16,335	10,890	8,168	6,534	5,445	4,667	4,084	3,630	3,267
36	14,520	9,680	7,260	5,808	4,840	4,149	3,630	3,227	2,904
48	10,890	7,260	5,445	4,356	3,630	3,111	2,723	2,420	2,178
Row-feet per acre	43,560	29,040	21,780	17,424	14,520	12,446	10,890	9,680	8,712

The equation for calculating the number of plants per acre is:

$$\text{Number of plants per hectare} = \frac{43{,}560\ \text{ft}^2}{\text{plant spacing in-row (ft.)} \times \text{between row (ft.)}}$$

Note: to apply the equation, convert in. to ft. (#in./12)

Seed factors

Germination percentage

The percentage of seeds that will germinate typically declines during storage, even under ideal conditions. This decline may be due to weakening caused by aging, damage, etc. It is important to use only high quality, vigorous seed with a high germination percentage.

Testing seed lots before planting for speed, uniformity and total per cent germination provides a reasonable estimate of how well the seed will perform in the field. You can adjust the seeding rate to a certain extent to compensate for a less vigorous seed lot. Over-seeding may require some thinning out later, which is costly.

Emergence is never perfect. Even with the best seed and the best seeding equipment under ideal field conditions, some crops must be seeded at rates that are double or triple the final desired stand. For example, if a 30-cm (12-in.) in-row spacing is desired for cabbage or cauliflower crops, it may be necessary to plant every 15 cm (6 in.) to ensure a near-perfect stand. In this situation, some thinning may be required.

Field factor

Planting conditions are seldom ideal. The soil may be too wet or too dry, too cold or too warm, too loose or too packed. A field factor is used to estimate how prevailing soil conditions will influence seedling emergence.

Under ideal conditions, a field factor of 0.8 (80 per cent emergence expected) can be applied. Under more typical conditions, a factor of 0.6 to 0.7 is common. Under still poorer conditions, the factor can be 0.5 or 0.4 or even lower. Irrigation improves germination, so the field factor will be higher than for dryland production.

The field factor applies to viable seeds only. If the germination rate of a seed lot is 80 per cent and the field factor is 0.7, then only 56 per cent of the seeds sown will emerge from the ground:

0.8 x 0.7 = 0.56 or 56 per cent

To compensate for the combined effects of the germination rate and the field factor, it may be necessary to substantially increase the seeding rate. This increase may mean using equipment that will either drop two seeds per hole, rather than just one, or drop seed through twice as many holes.

Different kinds of disk seeders on display
Photo: Robert Spencer

Achieving accurate plant density

By considering the influence of seed and environmental factors on seed germination, you can achieve some control over your final plant population. Additional options to help you get close to your target plant populations include using precision seeding equipment or using transplants.

Precision seeding

Precision seeders have been in use in vegetable crop production for many years. These seeders have been developed for virtually all vegetable crops and seeding situations.

Precise placement of the seed in the row improves the quality of the product by enabling uniformly spaced plants to develop at the same rate. The production of root crops such as carrots and onions has benefited the most from precision seeding because the resulting uniform plant spacing reduces grading and packing problems and creates fewer culls.

Further benefits of precision drilling are that less seed is required, and thinning may be reduced or eliminated. Precision seeding becomes more important as the price of seed increases, especially with the increased use of high-cost hybrid seed.

Despite the increased precision possible with the use of precision seeding equipment, lack of attention to any of the factors that influence germination and emergence (e.g. seed size, seeding depth, etc.) or improper equipment operation or calibration can produce results that are no better than those achieved using more conventional seeding methods.

Belt seeders

One of the most common types of precision seeder is the belt seeder. Belt seeders can be used for most vegetable crops. They offer the advantage of being able to seed crops like carrots in wide 7.5- to 10.0-cm (3- to 4-in.) multi-row bands as opposed to narrow single rows. Often, more plants can be grown and harvested per unit of row when seeds are planted in a wide band.

Crops well suited to seeding with a belt seeder and the type of belt required for each, if raw seed is used, are listed in Table 13.

Row configuration refers to the number of rows of holes cut to accommodate seed on each seed belt. Ideal row configuration for vegetable crops may vary based on the market intentions for the crop. Table 14 provides recommended row configurations for various vegetable crops.

The distance between seed drop from each line varies from 1 to 7 cm (0.5 to 3.5 in.) depending on the type of coulter used.

Table 13. Belt type requirements for various vegetable crops

Crop type	Belt type	
Asparagus	Rubber	Single rib
Beets	Rubber	Triple rib
Broccoli	Rubber	Smooth
Cabbages	Rubber	Smooth
Carrots	Plastic	
Cauliflower	Rubber	Smooth
Corn (sweet)	Rubber	Single rib
Cucumbers	Rubber	Smooth
Lettuce	Plastic	
Onions	Rubber	Smooth
Parsnips	Rubber	Smooth
Rutabagas	Rubber	Smooth

Table 14. Row configuration of different vegetable crops

Crop type	Row configuration
Asparagus	Single line
Beets	Twin line
Broccoli	Single line
Cabbages	Single line
Carrots	Twin or triple line
Cauliflower	Single line
Corn (sweet)	Single line
Cucumbers	Single line
Lettuce	Single line
Onions	Twin line
Parsnips	Single line
Rutabagas	Single line

Disk or plate seeders

These types of seeders can range from fairly primitive and inexpensive to more complex. However, these seeders will do an adequate job of seeding for smaller to larger operations.

Disks or plates with different-sized and spaced holes allow seed to drop at different rates. Proper calibration and consideration of different seed sizes and shapes are necessary for accurate planting with certain models.

Vacuum seeders
In these seeders, the seeds are drawn against holes in a vertical plate using a vacuum and agitated to remove excess seed. Seed should not be coated. Seeds of different crops (different sizes) can be seeded using this type of seeder.

Vegetative propagation material

Vegetative propagation involves establishing the crop using either whole plants (seedlings) transplanted into the field or using plant parts such as tubers, bulbs, rhizomes, crowns or corms. For information on using transplants, see the following section on Transplanting.

The use of vegetative propagation to establish a plant stand has a number of benefits relative to seeding directly into the field (direct seeding). Some crops, such as garlic, can only be produced from vegetative material (there is no such thing as garlic seed). Other crops, such as onions, can be grown from seed, but will produce more consistent and higher yields with better quality in a shorter time when grown from vegetative material.

Crops grown from plant parts are exact genetic duplicates of the mother plants. Thus, they are uniform and should perform consistently.

When using vegetative material to establish a crop, many of the same principles apply as when the crop is established from true seed. Make sure the propagation materials are spaced appropriately, with consideration for their final size. Overplanting is rarely necessary as most vegetative materials are more robust than true seed. Planting depth is very important to ensure that plants develop correctly and emerge quickly.

Plant parts need to be oriented correctly at planting for optimal growth. For example, place bulbs with roots facing downward and tips upward to encourage rapid development.

Plant vegetative material into warm soil with adequate moisture. It is critical to avoid having the expensive vegetative material sitting for

Plate seeder
Photo: Robert Spencer

Vacuum seeder
Photo: Robert Spencer

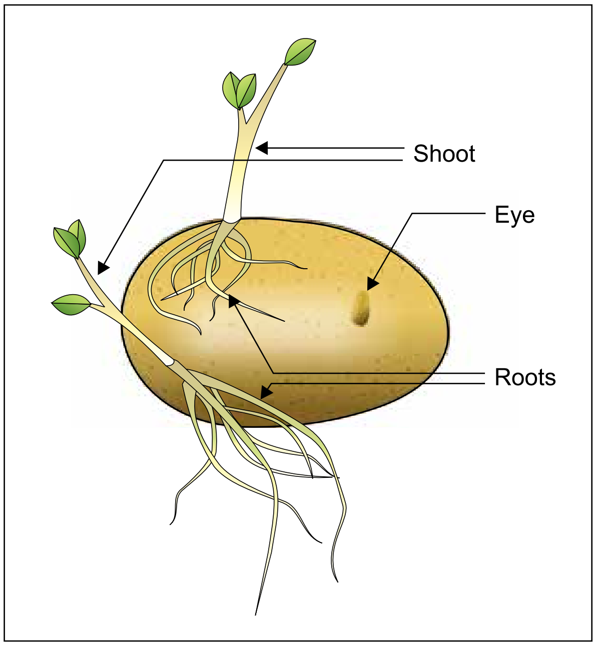


Figure 3A. Drawing of potato tuber

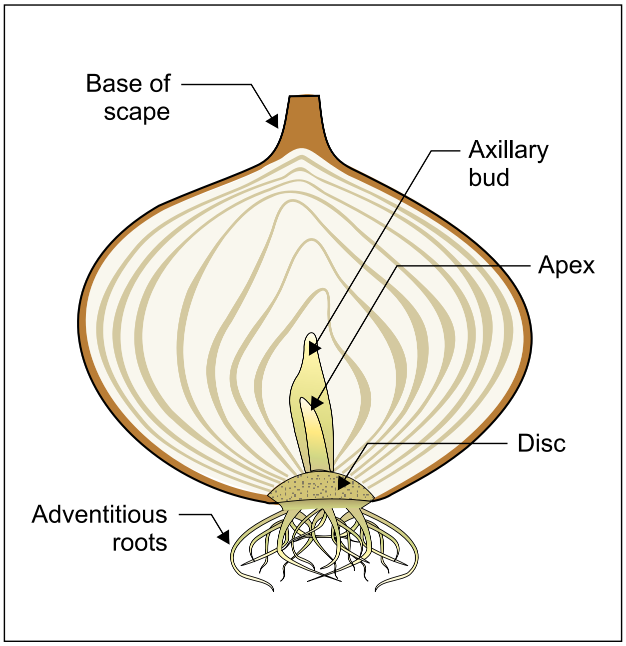


Figure 3B. Drawing of onion bulb

extended periods in cold, wet soil as this situation will lead to disease.

Some priming (or a sort of pre-planting pre-germination) can be done on some material, such as tubers. However, once growth processes are started, place the material in the ground promptly. Vegetative material is perishable due to its higher moisture content.

Only plant quality material. Nothing you do after planting will improve the quality of the material placed in the ground.

Compared to true seed, vegetative propagation material has an increased risk for the introduction of pests, such as diseases, viruses, nematodes and insects, either in the material itself or in the soil associated with it.

The quantity of vegetative planting material required to achieve a specific plant population varies depending on the desired plant spacing and the size, quality and vigour of the propagative material (Table 15).

Table 15. Plant material requirements for vegetatively propagated crops

Crop	Plant parts	Quantity*	
		(per ha)	(per ac.)
Asparagus	crowns	14,500-27,250 units	5,800-10,900 units
Garlic	cloves	900-2,240 kg	800-2,000 lb.
Jerusalem artichoke	tubers	1,120-1,340 kg	1,000-1,200 lb.
Horseradish	root cuttings	22,500-27,500 units	9,000-11,000 units
Onion	sets (bulbs)	560-1,120 kg	500-1,000 lb.
Potato	tubers or tuber pieces	1,450-2,900 kg	1,300-2,600 lb.
Rhubarb	crown divisions	10,000-12,500 units	4,000-5,000 units

* Quantity will vary with size of pieces, plant spacing and quality of plant material.

Transplanting

The advantages of using transplants to establish a vegetable crop are numerous:

- More complete plant stand: Placing a partially grown plant into the field reduces the risk of plant failure and ensures that you have plants where you want them.
- Reduced seedbed preparation requirements: While the seedbeds must be prepared to some degree before transplanting out the seedlings, the level of preparation may be less for transplants than for seed.
- Improved plant growth: Plants grown from transplants may have better root growth and establishment.
- Growing season extension: Using transplants gives the crop a head start. The resulting crop will mature earlier and can be marketed when prices are higher. Transplanting, in effect, extends the crop's growing season.
- Increased crop yield: The accelerated or enhanced growth achieved by using transplants can result in higher yields and reduced risk of crop loss to fall frost.
- Improved uniformity of harvested product: Crops grown from transplants are normally more uniform in size, shape and maturity, which can increase crop value while reducing harvest and grading costs.
- Enhanced plant maturation: Some types of vegetables will not typically mature if grown directly from seed in the field on the Canadian Prairies. Tomatoes, peppers, brussels sprouts, celery, eggplants, melons and other long and warm-season crops are examples of such late maturation. Transplants may increase the odds of the crop reaching maturity before frost.
- Avoid seedling issues: Transplants typically avoid seedling issues, such as damping-off, poor germination and emergence, insect predation, etc., because sensitive germination steps occur under carefully controlled greenhouse conditions. Also, transplants may be better able to withstand pest attacks. For example, newly emerging cabbage and other cole crop seedlings can be totally destroyed by flea beetles. The larger, tougher transplants can better tolerate flea beetle damage. This advantage is becoming more important as seed prices increase.
- Compatible with growth enhancement technology: Transplants can be grown with plastic mulch, row covers, drip irrigation, etc., which can result in increased growth, yield and returns.

Transplants are not cheap. However, purchasing transplants may be more dependable and cheaper than growing your own, unless you have the experience, equipment and facilities necessary for transplant production. If you are considering growing your own transplants, see the Transplant Production chapter.

Transplants are often used in conjunction with growing season enhancement or extension

Transplanter in operation
Photo: Robert Spencer

practices and technology, which will involve additional costs, training and specialized equipment requirements.

While the use of transplants can be advantageous, carefully consider the additional costs and skills required. Failure to properly care for transplants can result in poor establishment and growth, crop loss and wasted resources, negating any benefits that transplants provide.

Transplant establishment

To ensure that transplants are used to their maximum potential, be sure to provide suitable conditions for their growth, development and survival.

Hardening off

When transplants are taken from the ideal conditions in the greenhouse into the relatively harsh field conditions, they can experience shock, which can slow growth. Hardening off, or acclimation, is the process of gradually exposing transplants to less-than-ideal conditions for a short time before transplanting to reduce transplant stress.

Hardening off can be accomplished by the following steps:

- allowing plants to dry out slightly
- cutting back on applied fertilizer (especially N)
- placing plants outside, perhaps in direct sunlight and light wind, for short periods
- lowering or increasing greenhouse temperatures, depending on outside conditions

It is important not to over-harden plants as that condition can result in a severe check in growth and reduced quality in some crops (e.g. cole crops).

Soil preparation

The objective of soil preparation for a transplanted crop is to create a soil environment conducive to rapid root growth following transplanting. Cool soil temperatures can slow root growth and transplant establishment. High soil temperatures in summer plantings can cause girdling of the transplants at the soil surface. Irrigation soon after transplanting will cool the soil surface and help prevent girdling.

It is not necessary to have a finely prepared seedbed when transplanting most vegetables. It is better to minimize tillage to preserve the soil structure and moisture than to overwork the soil to get it perfectly smooth and clean. A rough field bed also helps reduce wind damage and physical abrasion of young transplants. Transplanting equipment can be modified with various implements to accommodate field conditions.

Soil moisture and fertility

Water and fertilizer are necessary for healthy root and plant growth, and transplant roots will not grow through dry soil in search of water or nutrients. Therefore, ensure there is adequate moisture and nutrients in the immediate root zone at the time of transplanting to meet the needs of the plants until the roots can access resources farther out. Apply water at transplanting (using a transplanter, if it is equipped) or irrigate thoroughly immediately after planting.

Other steps that increase the odds of transplants surviving dry soil conditions:

- tilling the soil as little as possible (each time soil is disked or dragged, valuable moisture is lost)
- hardening off transplants
- transplanting smaller rather than larger plants
- trimming off some of the leaves before transplanting
- watering the transplants before setting out in the field
- applying anti-transpirant treatments

If applying a starter fertilizer with the transplants, decrease the amount of soluble fertilizer in the starter solution by 50 per cent, making water more available to the plant. Depending on soil type, it may be possible to increase the volume of starter solution, but take care that plants do not float out of the furrow before the press-wheels firm the soil around the roots.

On sandy soils with high water infiltration rates, it is possible to double the amount of starter solution per plant with no planter problems. The additional water is beneficial under dry soil conditions for a short period but cannot sustain the plant for more than a few hours.

Irrigation before transplanting is very important to build the water reserve in the root zone, but be sure not to saturate the soil. Post-transplanting irrigation helps settle the soil around the roots, building the humidity around the leaves and cooling the soil when it is extremely hot. Different irrigation systems will accomplish these objectives in different ways and at different rates.

Transplanting
Transplanting should take place in cool, overcast conditions, if possible, to reduce the immediate stress on the transplants due to water loss from the leaves. If this condition is not possible, ensure that plants have sufficient moisture and nutrients before and after planting. Transplants waiting to be planted should be kept in shaded or sheltered areas to reduce moisture stress.

Depending on the scale of the field, transplanting can be done either by hand or mechanically. Regardless of the method used, make sure seedlings are placed in the ground properly, at the appropriate depth. Calibrate transplanting equipment properly prior to use, and further adjust it in the field, as required.

Depth of planting is critical. Most vegetable crops should be planted slightly deeper than they were in the greenhouse. The root ball should be completely covered with soil. Tomatoes are an exception and can be planted much deeper with no detrimental effects due to their unique ability to initiate adventitious (accidental) roots from the stem.

Workers must be instructed about proper handling and placement of transplants. Poorly trained workers can damage transplants by crushing stems, breaking off terminals or growing points and damaging the leaves, or by placing the transplants at the wrong depth.

Post-planting care
Carefully nurture transplants after setting them in the field to ensure that they establish quickly. Provide adequate, but not excessive, nutrients and moisture to the plants. Shelter them from strong, damaging winds and other stresses.

Fall seeding

While not a common practice, some vegetable crops can be field planted before the onset of winter on the Prairies. This practice, called fall or winter seeding, tries to give the crop an advantage in terms of early spring growth and maturity, leading to early market access and higher prices the following season.

The fall-planted crop is able to start growing before fields are typically accessible in the spring, or the crop may prefer the cooler, wetter conditions of early spring. Fall seeding is more likely to be done in smaller market garden operations.

Only crops with a high degree of frost tolerance are compatible with fall planting. Table 16 lists crops suited to fall planting.

Table 16. Vegetables suited to fall seeding

Crop	Advantages of fall seeding
Carrots	earlier sizing
Garlic	superior yields and earlier maturity
Lettuce (all types)	2 to 3 weeks earlier to maturity
Onions (cooking)	2 weeks earlier to 50% tops down
Parsnips	earlier sizing
Spinach	10 days earlier to optimum development as well as minimal bolting

Prepare the seedbed well in advance of fall seeding, and do the actual seeding as late as possible. The success of fall seeding depends mostly on soil temperature and moisture at the time of seeding. The seed must remain dormant in the soil, so there must be no free water available for uptake before freeze-up. Uptake of water by the seed before freeze-up will destroy viability.

In addition, the soil temperature at seeding depth must be 5°C (41°F) or colder. The time when this temperature occurs will vary with the region and the season. Visual signs, such as ice persisting throughout the day on ponds or frost evident during mid-day in the shade of buildings, help indicate that soil temperature is ideal for fall seeding.

Soil warms slowly, so a few warm days will do little to increase soil temperature. Growers should not get unnecessarily concerned over brief warm spells in late fall and winter.

Overwinter survival of a fall-seeded crop can be influenced by many factors. Generally, early and heavy snow cover enhances survival. As there will inevitably be some loss of seed viability over the winter, heavier than normal seeding rates are recommended to attain a good plant stand and yield. This requirement can prove to be costly, particularly when hybrid seed is used, so consider using less costly seed.

Table 17 indicates the percentage of seed that survives the winter and the recommended fall seeding rate.

Fall-seeded crops also have a higher risk of experiencing temperatures well below freezing early in the seedling stage, which can cause some physiological disadvantages. Carrots may bolt, onions may produce multiple growing points, and lettuce may fail to head properly.

The incidence of such physiological disorders is rare and is directly related to the duration and severity of low temperature exposure. A temperature of -8°C (18°F) or colder during the seedling stage appears to be the critical temperature for triggering a physiological abnormality.

Fall planting garlic

Garlic is one vegetable crop that is better suited to fall planting than spring planting. Fall planting allows garlic to begin development in early spring, before fields would normally be accessible. This extra development time results in higher yields and a superior quality product.

Experience has shown that planting date is not critical with fall-planted garlic. There is little effect on overwintering survival from planting as early as early September.

Good ground cover is critical to successful overwintering. If a good snow cover is not typical in your region, apply an insulating layer of straw mulch in fall.

Garlic varieties vary greatly when it comes to suitability for overwintering. Consult with your suppliers and run on-farm tests to determine whether a variety is suitable for overwintering in your area.

Table 17. Fall-seeded vegetable germination percentages and seeding rates, compared to spring-seeded recommendations

Crop	Recommended seed drop for spring seeding	Germination (%)		Recommended seed drop for fall seeding
		(per 30 cm or 12 in.)	(per 30 cm or 12 in.)	
		Spring-seeded	Fall-seeded	
Carrots	40	60-70	25-40	60
Lettuce	10	60-70	30-40	15
Onions (cooking)	18	70-80	40-50	30
Parsnips	15	70-80	25-35	25
Spinach	20	80-90	50-60	30

Water

Water is the lifeblood of all crop production and is a critical component of any vegetable crop operation. Vegetables are composed of over 80 per cent water, on average, and yields and quality are reduced whenever moisture becomes limiting. Thus, irrigation is a part of almost every vegetable operation on the Canadian Prairies.

As well, to preserve post-harvest quality, many vegetable crops are cooled using either water or ice. Most vegetables are sold after being washed, which again requires significant quantities of high quality water. Vegetables are also handled a great deal, often by hand. To prevent contamination and other food safety issues, washing and sanitation are critical steps.

Water for use in vegetable production and handling may come from lakes, ponds, rivers, streams, wells, dugouts (pumped or naturally filled) or municipal supplies. There are a number of important considerations when evaluating the suitability of a water source for vegetable production and handling.

Quantity

When evaluating water quantity, you will need to answer some key questions:

- What quantity of water is available for your use?
- How much water will you require in a given year for irrigation, cooling and washing?
- Can the water source provide sufficient water in a high demand year?

It is important to remember that a large volume of water is required to apply a seemingly small amount of irrigation water (such as 2.5 cm; 1 in.). If you are using a dugout, will it fill naturally and hold sufficient water in a given year for the anticipated demand? Are there ways to stretch your water supply, either through more efficient delivery systems or through careful rationing of the water into critical use periods?

For information on irrigation water quantity needs, see Water Use Requirements in the Irrigation Management section further on in this chapter. For information on water supply development and conservation, contact an agricultural water specialist.

Quality

You will also need to answer some important questions about water quality: is the water's quality suitable for irrigation, cooling and/or washing? Water for washing hands or produce and for cooling produce must be of potable quality. If water is being used for irrigation, it may not need to be potable, but it should not harm the soil or the crop. Is the quality consistent all year round? Freedom from contaminants (biological, chemical, etc.) is a must.

Some initial testing will be required to determine the suitability of the water. Potability and irrigation suitability evaluations require different tests. Water testing can be done at many of the same laboratories that do soil testing. Testing will need to be repeated at different times in the production cycle, as water quality can change throughout the season and over the lifespan of a vegetable operation.

Water quality is a critical component of all on-farm food safety systems (OFFS). For more information on water and OFFS, see the section on Food Safety in the Business Management chapter.

Water licensing

You must have a water licence to legally use a water source for your agricultural operation. Physical access to a particular water body does not mean you can legally use the water.

All provinces have a process whereby parties can apply for and receive a licence to use a specific quantity of water from a specific water body for the purpose of irrigation. Although the process and regulatory body may vary from province to province, the general requirements will be as follows:

1) **Land classification**: The land that is going to be used must be suitable for irrigation, meaning it must fit within appropriate physical guidelines relating to soil quality characteristics, such as texture, salinity, etc.

2) **Project feasibility**: If the land is suitable for irrigation, the next stage is to determine whether the actual irrigation project will be feasible on the land. The agricultural feasibility of the project must be proven through the collection of data. Will the application of water have a significant effect on the soil or land in question? Will the removal of the water for irrigation affect the water source of others who use or rely on the water source?

3) **Project effect on fish and wildlife**: This stage of the water licensing process involves applying and providing information to the federal Department of Fisheries and Oceans to account for any effect that the project (construction, water removal, etc.) will have on both the water source and the aquatic habitats that may occur within it. What effects, if any, will the project have on any wildlife within the area or region?

4) **Water licensing:** This stage of the process involves the actual application to the regulatory body that issues water licences. This stage would include submitting the information gathered during the investigatory stages of the process as well as an outline of the anticipated water uses for the operation. Any other conditions or issues would have to be resolved before approval and the issuing of the licence. Typically, water licences are attached to the land title, so the licence might go with an operation if it was sold. For full details on the process of water licensing in your province, consult your provincial government offices.

If you are considering applying for a water licence for your vegetable operation (whether a new operation or an expansion of existing activities), be sure to allow sufficient time for the licensing process, as it can be time consuming. Additionally, there will likely be costs associated with each stage of the process, as professionals will have to be contracted to do the analysis and information gathering stages.

Irrigation

Irrigation is a critical component of most field vegetable operations, although not all vegetables are irrigated. The ability to irrigate provides many advantages to vegetable production, even if the average annual precipitation is technically sufficient for vegetable production.

Table 18 outlines the advantages and disadvantages of irrigated versus dryland production.

Table 18. Advantages and disadvantages of irrigation

Advantages	Disadvantages
• increased yields and improved produce quality • enhanced control over maturity • precision control of moisture delivery and availability – moisture delivered when and where it is required • ability to deliver nutrients to the crop	• in wet years, limited yield benefit • potential for excess application of moisture, if irrigation applications are not properly managed • significant set-up, maintenance and operation costs associated with irrigation systems • potential for the introduction of poor quality water onto land • potential for introduction of contaminants • potential for soil quality reduction over time

Costs

Consider all components of an irrigation system when comparing systems and determining the costs of building, operating and maintaining an irrigation system. The cost of irrigation can vary greatly, depending on a number of factors:

- site and land preparation required to match the needs of the irrigation system (e.g. canals, three-phase power, buried supply pipes, land drainage and levelling)
- the type of system being used (e.g. pivot, solid set, drip, etc.)

- the size of the system (area being irrigated) and irrigation demand (amount of water used for any one application)
- water and water delivery costs (e.g. water, pumping, etc.)

The initial set-up and installation of the irrigation system will require significant capital, with costs for operation and maintenance continuing over time. As a general rule, the first acre is the most expensive, with additional expansion building off of some of the costs for that initial area. Consult an irrigation specialist and/or irrigation supplier to assist you in system set-up and design.

The operating costs of irrigation vary from year to year, mainly in response to the amount of water required by the crop.

Irrigation systems

There are many different types of irrigation systems, each with its advantages and disadvantages.

The selection of an irrigation system will depend on the topography, type of soil, water supply, crops to be grown, size of the field, and the amount of capital and labour available. Carefully consider what you need from your irrigation system, as well as compatibility with your current operation and future expansion needs.

The merits and limitations of some irrigation systems are discussed below.

Sprinkler

Several types of sprinkler irrigation systems are in use today. The efficiency level of these systems varies due to the potential for evaporative losses from the air as well as from the soil. However, sprinkler system technology has advanced significantly, allowing producers to accurately and more efficiently deliver water to the crop with minimal wastage and loss.

Mobile sprinkler set-up
Photo: Robert Spencer

Sprinklers are adaptable to almost any soil or topographic condition and can apply variable amounts of water, including the small, fine applications required to promote germination. They can also be used to apply water for other purposes, including frost protection or delivery of inputs (fertilizers, pesticides). However, the capital and operating costs of sprinkler systems can be quite high.

Solid set/hand move

Solid set/hand move sprinkler systems consist of portable aluminum pipes that are placed in the field semi-permanently, with sprinkler risers placed sporadically throughout the field. Due to their high cost, these systems are best suited to small acreages such as market gardens.

Solid set sprinkler irrigation
Photo: Robert Spencer

Solid set irrigation is capable of delivering a fairly uniform amount of water to the crop area, in set amounts. The amount of water delivered depends on the length of the irrigation period and the size of the sprinkler nozzles. These systems can be used at the germination stage if the pressures are high enough to provide a fine droplet size. Solid set systems can be designed to protect the crop against spring and fall frosts.

The capital costs associated with solid set systems may be less than some other sprinkler systems, depending on the size of the system (number of pipes). The main labour involved is the opening and closing of valves, with some set-up and take-down costs. On small acreages, the pumping unit is the main initial cost of any sprinkler system.

In some cases, the system can be left in place for the duration of the season. The system is typically removed at the end of the season for winter storage. Depending on the field layout and how much pipe is present, sprinklers and pipes may need to be moved periodically throughout the season to allow equipment access or to allow small applications of water to specific areas. These added procedures create additional labour requirements and costs for producers.

Wheel move

This type of system involves a series of sprinklers on a wheel-mounted pipe that is either hand moved or motor driven. The system is moved across a field, typically from one set position to another. The amount of water delivered depends on the length of the irrigation period and the size of the nozzles. Where surface crusting is a problem or when irrigation for germination is required, the nozzle size of the sprinklers can be reduced to produce a finer droplet size.

This system is most compatible with rectangular fields. Equipment costs vary depending on the number of laterals required. For vegetable crops, four 400-m (1/4-mile) long laterals per quarter section are required for high yield and quality.

Wheelmove irrigation system
Photo: Robert Spencer

Although smaller areas can be irrigated using this type of system, the unit cost is higher. If the field is not rectangular, the relative labour requirements are increased. This system has the flexibility to move on and off a field in smaller acreage situations.

Centre pivot

A centre pivot irrigation system consists of a rotating overhead pipe system that pivots in a circle around a central point. These systems are suited to vegetable crops provided a large area free of obstructions is available.

Pivot sizes can vary. Pivots covering a quarter section are most common but shorter centre pivots are available (at a higher per acre cost).

Pivot systems require limited labour; they can operate on rough topography, and their speed can be varied to permit light applications and thus improve water management. Pivots are limited in the maximum amount of water they can deliver in a given time, but flexible below that amount. Some adjustment may be required to deal with the tracks made by centre pivot towers. Vegetable producers may want to consider planting and harvesting in a circle.

An example of centre pivot irrigation
Photo: Robert Spencer

Traditional pivots use tower-mounted sprinklers with an end gun. These units used to operate best at high pressure and were consequently expensive to run and fairly inefficient due to evaporative losses.

In recent years, there has been a shift to higher efficiency, low-pressure systems. In low-pressure systems, drop tubes and spinning or rotating nozzles deliver the water just above the crop canopy in large droplets resulting in minimal evaporative loss. The height of the drop tube can be adjusted upwards as the crop grows. Some nozzle types can be used to deliver the water directly to the soil surface in some crops. The end gun is a high-volume sprinkler/cannon that delivers water to the areas beyond the end of the pivot system.

Linear pivot

Although similar to centre pivots in most ways (design, appearance and the ability for continuous movement), linear pivots move up and down a rectangular field in a way similar to a wheel move system. Linear pivots can operate as a lower pressure system, when low-pressure nozzles are used. Linear pivots are more expensive systems.

Traveling volume guns

A volume gun is a single, large sprinkler that discharges from 0.2 to 1 m^3/minute (100 to 500 US gallons/minute). These systems may be self-propelled or stationary, being set up and operated in one spot and then moved to a new location.

Due to the high water application rates and large droplet size, volume guns may damage tender young crops. Volume guns require a high operating pressure and, therefore, have high energy costs. However, they are very adaptable to odd-shaped fields, tall crops or infrequent, occasional use situations.

Travelling gun irrigation system
Photo: Robert Spencer

Travelling volume gun and reel system
Photo: Robert Spencer

Cucumber seedlings with drip line irrigation
Photo: Robert Spencer

Drip irrigation line
Photo: Robert Spencer

Drip

Drip irrigation, also called trickle irrigation, involves applying water to the rows at or below the soil surface at a slow rate through a network of supply lines. This process results in a more or less continuous wetting strip down the row, depending on the distance between the emitters or the type of supply system used. Only the row is irrigated, with between-row spaces remaining dry, which means water is not wasted on non-crop areas.

Drip irrigation operates at a very low pressure, with typical operating pressures at 70 to 200 kilopascals (kPa) (10 to 30 pounds per square inch (psi)). Drip irrigation is ideal for vegetable production where the water supply is limited as producers can expect water savings of 30 to 70 per cent compared with furrow or sprinkler irrigation. This saving is due to efficiencies gained by reducing evaporative losses as well as reducing the total area being watered. Placing the tubing in the seed row will further reduce water use and help control weeds.

Drip irrigation is highly compatible with the use of plasticulture, as it can be used under plastic mulch and/or row or field covers. It is also very compatible with fertigation because soluble fertilizers can be delivered directly to the plants. Drip irrigation can also reduce the incidence of foliar diseases as there is no wetting of the foliage. Drip irrigation systems cannot provide frost protection.

With other types of irrigation, a small amount of forgiveness may exist in terms of water quality characteristics like small particles or other debris. However, even fine particulates or debris will plug the very small emitters that deliver the water in a drip system. Once plugged, these emitters are very difficult to clean. Water filtration may be able to remove the particles. The type of water filtration needed depends on the initial water quality and the type of drip line used.

When designing a drip system, consult an expert for assistance. The high capital costs of equipment may limit the use of drip irrigation in large field installations. Be aware of the delivery capabilities and limitations of your system to ensure that sufficient moisture can be delivered to your crops.

There are also limitations on the length of a drip line and the number of lines that can be run simultaneously with a given pressure. You may need to plan or set up your system in quadrants or sections off a main supply system. For larger fields, a single line may not be sufficient.

For crops such as carrots, tomatoes and cucumbers, a double-row crop configuration with one drip line between the closely spaced double rows may be appropriate. This set-up requires less tubing and has a higher plant population than a single-row configuration.

Surface

Surface irrigation occurs when water is released to flow over the surface of the field, typically controlled only by gravity. Surface irrigation includes flood and furrow irrigation. Surface irrigation design and layout depend on the crop to be grown, slope of the terrain, soil type and water supply. Surface irrigation of vegetable crops is usually done by the furrow method.

With furrow irrigation, the irrigation water flows down furrows that run parallel to the crop rows. Movement of water into the soil is both lateral and vertical. The distance that water moves, both laterally and down through the soil, depends greatly on the soil type. In most cases, the irrigation of alternate furrows will give results almost equal to irrigating every furrow.

From a practical standpoint, land slopes for furrow irrigation should be less than 2 per cent and preferably less than 1 per cent for efficient water application. Usually, levelling is required for furrow-irrigated fields to eliminate low spots where water would otherwise pond.

Precise water control into the furrows can be maintained with siphons or gated pipe because furrow stream sizes can be adjusted to fit the particular need. The use of gated pipe eliminates seepage and weed problems associated with open, unlined supply ditches.

Flood and furrow irrigation are on the low end of the water use efficiency scale. There are significant evaporative losses, and unless plants are very close together, water use is inefficient. The ability to precisely control water delivery is very limited in furrow irrigation compared to other delivery systems. This type of irrigation is not very common anymore, although some areas still use this method or a variation of it.

Irrigation system design

If you are planning to add or expand an irrigation system, consult with an irrigation engineer and/or contact an irrigation supplier for assistance in designing the system, including pumps, supply networks and delivery equipment. This consultation should also include a plan for obtaining the proper licence for utilizing the water source.

Fertigation

Fertigation is the application of dissolved fertilizer nutrients through an irrigation system. This practice can be used with almost any type of irrigation system, although the efficiency of delivery will vary.

It is best suited to the application of small amounts of readily available (soluble) nutrients (such as nitrogen) to supplement existing fertilizer supplies. Large amounts of fertilizer are not typically applied via an irrigation system because all applied nutrients are associated with a significant volume of water.

When using fertigation, consider applying fertilizers at the beginning of an irrigation cycle, with a period of fresh water at the end of the application. This practice allows the system to be flushed following the fertilizer, reducing corrosion of the system by fertilizer salts. It also moves the soluble fertilizer further throughout the soil profile, preventing a buildup of excessive salts in the root zone.

Take care to prevent backflow and siphoning of fertigation water, which can result in contamination of the water source. Because of the corrosion risk, maintenance of the irrigation system is especially important to ensure it continues to function properly.

Refer to Fertilizer Application Methods in the earlier Fertility section for more details on the use of fertigation.

Irrigation management

With increasing global demands on quality, fresh water resources, producers need to focus on careful, efficient and precise use of irrigation water. Be aware of the limitations and efficiencies of your irrigation system and ensure it is functioning at maximum efficiency. As well, try to ensure that your crops use the supplied water to the maximum benefit, with the least amount of waste.

Various practices and technologies are available to improve irrigation effectiveness and efficiency. You will need to understand the relationship between your soil types, crop types, type of irrigation system and the changes or fluctuations in irrigation water requirements that occur on a daily, weekly, monthly and/or annual basis.

Water use requirements

Adequate and timely irrigation produces high yields and top quality produce. Either too much or too little irrigation can delay growth and maturity and, in some cases, may encourage the development of disease or soil salinity.

The amount of water a crop can and will use (and the subsequent irrigation requirements) varies depending on a number of factors:

- climatic factors: temperature, humidity, sunlight, wind, precipitation
- crop factors: plant populations, crop size, crop stage, crop type
- soil factors: soil texture, soil water-holding capacity, soil moisture reserves

Climatic factors

Generally, crop water demand will increase as temperature, wind and sunlight increase and humidity decreases. These conditions increase the evaporative water loss from the soil and the water loss from the plant via evaporation and transpiration. The absence of precipitation will necessitate irrigation applications.

In some cases, irrigation can have a temporary influence on microclimate factors within the crop canopy such as temperature and humidity, which can temporarily reduce plant water demand. Larger or heavier applications of water will wet the soil to a greater depth and provide more water for the plant to draw in.

Regularly collect climatic information on your operation to make the best irrigation management decisions. At a minimum, measure the moisture received by precipitation or irrigation. Collecting other weather data, like daily temperatures and wind conditions, can be beneficial as well. Data from your local weather station may provide a general idea of the weather in your region, although it is not specific to your operation.

Crop factors

By understanding your crop's specific moisture needs, you can more closely manage irrigation and maximize crop productivity and produce quality. For example, the tubers and bulbs of some crops such as potatoes and onions have higher dry matter contents when they receive sufficient irrigation throughout the growing season. But by also reducing late-season moisture application on these same crops, producers can maximize dry matter content. Each crop is different in its moisture requirements.

A crop's ability to access water and the total amount of moisture available to the crop will vary depending on the crop's rooting depth and the amount of soil the roots come in contact with. These factors can directly relate to the crop's water-use requirements.

The allowable depletion of soil moisture is the level of dryness that the plants can experience while still producing the desired yield. This level of dryness is usually expressed as the percentage of available moisture in the root zone. See Table 20 in the Soil Factors section.

Allowable depletion varies with the crop type and, to a lesser extent, the crop stage. For example, crops with a deep and extensive fibrous root system can seek out water from a greater soil volume, reducing their watering requirements, or at least the frequency with which they must be irrigated. Crops with a single, narrow taproot or seedlings with their small root systems are only able to take up water from a relatively small soil volume, so they need water more frequently.

The available moisture in a root zone can be estimated by the hand-feel method (see the Appendix), or by using various soil moisture determination tools (see the upcoming Soil Moisture Determination section). Soil texture influences the amount of water that can be held in a given volume of soil (see the next section, Soil Factors).

Water must not only be supplied in sufficient quantity to meet crop needs, but must also be supplied in a way that is of most use to the crop (e.g. applied near the root zone). Therefore, both crop stage and rooting depth will influence a crop's irrigation requirements. Table 19 outlines typical rooting depths and general water requirements of various vegetable crops, as well as their critical periods for water use.

All crops differ in their rate of development, and each crop growth stage has differing moisture requirements. For example, seedlings require relatively small amounts of moisture because they are small. However, their small size means they only have access to water in a small soil volume, so the soil must be kept relatively moist.

Older, more mature plants have a greater moisture demand, but they can usually tolerate drier soil. Older plants typically have extensive, or at least larger, root systems, so they can draw moisture from a larger area to meet their needs.

Crops have stages in their development when sufficient moisture is absolutely critical to healthy crop development (Table 19). Deficiency in moisture at these sensitive stages will result in dramatically reduced yield and quality. Some crops have multiple critical periods, although the length of these periods may be brief. If water supplies are limited, conserve water for use at those critical stages to prevent crop failure, although overall crop productivity may be reduced.

The most critical periods to avoid moisture stress are during seedling emergence and during the formation of the tissues that will be harvested, for example, during flowering of tomatoes and peppers, during tuber initiation of potatoes and during the elongation of the taproot in carrot. Inadequate irrigation during these critical periods will cause low yields and poor quality produce.

As a general rule, most vegetable crops benefit from about 2.5 cm (1 in.) of moisture on a weekly basis, whether from precipitation or irrigation.

In addition to attempting to meet specific crop water requirements, irrigation may be applied in differing amounts, depending on the purpose of the application. For example, small-seeded vegetable crops may require light, frequent applications of water to encourage the emergence of the seedlings.

This practice is particularly important in soils where crusting is a problem. Small applications of water should wet the top layer of the soil. A depth of 10 mm (0.4 in.) of water per application should be sufficient. If more water is applied, it will increase the likelihood of crusting and will not keep the soil surface moist longer than a small application.

Light applications can be successfully achieved using sprinkler irrigation systems equipped with fine nozzles operating at high pressure. It is important to use an irrigation system designed according to the needs of the crop. Proper sizing of sprinkler nozzles operating at the designed system pressure will ensure a uniform application of water.

Table 19. Water requirements of vegetable crops

Crop	Rooting depth		Allowable depletion of available moisture* (%)	Critical period for water use	Water requirements	Other comments
	(m)	(ft.)				
Asparagus	1.2+	4+	60	Establishment and harvest	Apply 25 mm (1 in.) every 10 days (depending on precipitation)** Apply about 50 mm (2 in.) after harvest** Apply 25 mm (1 in.) at the end of the season**	
Beans	0.9	3	40	Flowering and pod set (seed formation)	Apply 25 - 38 mm (1 - 1.5 in.) per week during peak use period**	A waterlogged soil during flowering or pod formation will reduce seed yields and encourage disease development
Beets	0.9	3	50	Root expansion	Apply about 25 mm (1 in.) every 2 weeks**	
Carrots	0.9	3	40	General growth and root enlargement	Will use 4 - 6 mm (0.16 - 0.24 in.) per day during peak use period**	Several small applications of water near time of emergence will help obtain a uniform stand. In the fall, an excessively wet soil will encourage development of soft rots
Cole crops (broccoli, cabbages, cauliflower)	0.75	2.5	35	Sensitive at all stages, but particularly during head formation and enlargement	Will use 380 - 500 mm (15 - 20 in.) during the season** Apply about 25 mm (1 in.) every 5 - 10 days**	

*A crop that has an allowable depletion of 25% of the available moisture will require irrigation twice as often as a crop that has an allowable depletion of 50%, if they have the same rooting depth and daily water use. Available moisture is the water held in the root zone between field capacity and permanent wilting point. In general, vegetable crops are more sensitive to water deficiency during emergence, flowering and early produce formation than they are during early (vegetative) and late growth periods (ripening).

** Including precipitation

Continued

Table 19. Water requirements of vegetable crops (continued)

Crop	Rooting depth		Allowable depletion of available moisture* (%)	Critical period for water use	Water requirements	Other comments
	(m)	(ft.)				
Corn (sweet)	1.0	3.2	40	Tasseling, pollination and ear filling (from tassel to seed formation)	Will use up to 6 mm (0.24 in.) per day (during peak use period) Will use up to 510 mm (20.4 in.) during the season**	
Cucumbers	0.6	2	50	Flowering, fruit set and development (during rapid growth and fruit sizing)	Apply 25 mm (1 in.) after seeding/ transplanting Do not allow to dry out during critical period Will use about 200 - 250 mm (8 - 10 in.) during the season**	Available soil moisture should be kept above 60% after flowering begins
Eggplants	0.4 - 0.6	1.5 - 2	50	Flowering, fruit set and enlargement	Apply 25 mm (1 in.) per week**	
Garlic	0.6	2	35	Bulb formation and enlargement	Apply 25 mm (1 in.) per week (minimum)**	
Lettuce	0.6	2	25	Germination and throughout growth Head lettuce is sensitive to moisture stress during head formation	Do not allow soil profile to become depleted	Excessive moisture in the seedling stage may cause plants to die off

*A crop that has an allowable depletion of 25% of the available moisture will require irrigation twice as often as a crop that has an allowable depletion of 50%, if they have the same rooting depth and daily water use. Available moisture is the water held in the root zone between field capacity and permanent wilting point. In general, vegetable crops are more sensitive to water deficiency during emergence, flowering and early produce formation than they are during early (vegetative) and late growth periods (ripening).

** Including precipitation

Continued

Table 19. Water requirements of vegetable crops (continued)

Crop	Rooting depth		Allowable depletion of available moisture* (%)	Critical period for water use	Water requirements	Other comments
	(m)	(ft.)				
Muskmelons, cantaloupes	0.3 - 0.6	1 - 2	40	Flowering, fruit set and development	Apply 25 mm (1 in.) after seeding / transplanting ** Do not allow to dry out during critical period	
Onions	0.6	2	35	Bulb formation and enlargement	Will use 4 - 5 mm (0.16 - 0.2 in.) per day (during peak use) Apply 25 mm (1 in.) per week** Will use 350 - 500 mm (14 - 20 in.) during the season**	Light applications may be needed early in the spring to aid emergence Do not water after the third week of August to allow time for drying down of bulbs
Parsnips	1.0	3.2	40	Root expansion	Apply about 25 mm (1 in.) every 2 weeks **	
Peas	0.6	2	30	Flowering, pod set and fill	Will use 5.5 - 6 mm (0.22 - 0.24 in.) per day (during peak use) Will use 375 mm (15 in.) during the season**	Peas are sensitive to waterlogged soil
Peppers	0.9	3	30	Flowering, fruit set and enlargement	Apply 25 mm per week** (depending on soil type)	Moisture stress will reduce yields and can contribute to blossom end rot
Potatoes	0.8	2.5	30	Tuber initiation and sizing (from flowering until vine ripening)	Will use 5.5 - 6 mm (0.22 - 0.24 in.) per day (during peak use) Will use up to 550 mm (22 in.) during the season**	Keeping soil moist at time of tuber formation increases number of tubers formed but reduces the average size of tubers Late potatoes that do not suffer moisture stress will have higher dry matter content than potatoes grown under an intermittent water supply

*A crop that has an allowable depletion of 25% of the available moisture will require irrigation twice as often as a crop that has an allowable depletion of 50%, if they have the same rooting depth and daily water use. Available moisture is the water held in the root zone between field capacity and permanent wilting point. In general, vegetable crops are more sensitive to water deficiency during emergence, flowering and early produce formation than they are during early (vegetative) and late growth periods (ripening).

** Including precipitation

Continued

Table 19. Water requirements of vegetable crops (continued)

Crop	Rooting depth		Allowable depletion of available moisture* (%)	Critical period for water use	Water requirements	Other comments
	(m)	(ft.)				
Pumpkins	0.6 - 1.2	2 - 4	60	Flowering, fruit set and development	Apply 25 mm (1 in.) after seeding/ transplanting** Do not allow to dry out during critical period	
Radishes	0.3 - 0.4	1 - 1.5	30	Root fill	Do not allow to dry out	
Tomatoes	0.9	3	40	Flowering, fruit set and enlargement	Apply 25 mm (1 in.) per week*	Moisture stress will reduce yields and can increase the incidence of blossom end rot
Zucchini	0.4 - 0.6	1.5 - 2	30	Flowering, fruit set and development	Apply 25 mm (1 in.) after seeding/ transplanting** Do not allow to dry out during critical period	

*A crop that has an allowable depletion of 25% of the available moisture will require irrigation twice as often as a crop that has an allowable depletion of 50%, if they have the same rooting depth and daily water use. Available moisture is the water held in the root zone between field capacity and permanent wilting point. In general, vegetable crops are more sensitive to water deficiency during emergence, flowering and early produce formation than they are during early (vegetative) and late growth periods (ripening).

** Including precipitation

Soil factors

Soil texture has a direct effect on the moisture available for crop use in terms of soil moisture-holding capacity (Table 20). Coarser-textured soils (lighter soils, e.g. sandy soils) have a lower capacity to hold plant-available moisture than finer-textured soils (heavier soils, e.g. clay soils).

Table 20. Soil texture and capacity to hold plant-available water

Soil texture	Available moisture	
	(mm of water/10 cm depth of soil)	(in. of water/1 ft. depth of soil)
Loamy sand	8 - 12	0.9 - 1.4
Sandy loam	10 - 15	1.2 - 1.8
Loam	14 - 18	1.7 - 2.2
Sandy clay loam, clay loam, clay	15 - 20	1.8 - 2.4
Silty clay loam, silt loam	16 - 22	1.9 - 2.6

Soil texture affects irrigation timing and amounts by its influence on available moisture. For instance, consider an onion crop growing in a loam soil (Table 21). Onions can only effectively draw moisture from a 0.6-m (2-ft.) depth of soil. If the soil moisture depletion exceeds 35 per cent, onion yields are reduced.

In this example, the loam soil has a water-holding capacity of 17 mm of water per 10 cm depth of soil (2 in./ft.). So if the soil moisture is at field capacity, then the loam soil will have 102 mm (4 in.) of moisture available for the onion crop's use in a 0.6-m (2-ft.) depth of soil. Since the allowable depletion is 35 per cent, then 36 mm (1.4 in.) of water can be removed from the root zone before irrigation will be required.

In mid-summer, the consumptive water use for onions is about 5 mm (0.2 in.) per day. At this rate of use, irrigation will be required every 7 or 8 days (assuming no rainfall occurs, and normal crop growth and development are taking place), with a net application of 36 mm (1.4 in.) of water.

Another example is a carrot crop growing in a sandy loam soil (Table 21). Carrots have an effective rooting depth of 0.9 m (3 ft.). If the sandy loam soil has a water-holding capacity of 13 mm/10 cm (1.5 in./ft.) and if soil moisture is at field capacity, then the soil will have 117 mm (4.5 in.) of water available for the carrot crop's use in a 0.9-m (3-ft.) root zone.

Since the allowable depletion level for carrots is 40 per cent, then 47 mm (1.8 in.) of water can be depleted from the root zone without putting the crop under stress. Moisture use by carrots will vary from 3 mm/day (0.12 in./day) toward the end of June to about 6 mm/day (0.24 in./day) at the end of July.

Remember that crop water use will increase with hot or windy weather and decline in cool periods, and that weeds will increase water loss or removal from the soil. Therefore, irrigation scheduling needs to be based on a determination of the actual soil moisture content, as described in the next section.

Table 21. Irrigation scheduling examples for some vegetable crops

Crop, rooting depth	Soil water-holding capacity	Available moisture held in root zone*	Allowable depletion (%)	Moisture safely depleted	Daily water use	Irrigation frequency
Onions 0.6 m (2 ft.)	loam 17 mm/10 cm (2.0 in./ft.)	102 mm (4 in.)	35	36 mm (1.4 in.)	5 mm (0.2 in.)	7 days
Carrots 0.9 m (3 ft.)	sandy loam 13 mm/10 cm (1.5 in./ft.)	117 mm (4.5 in.)	40	47 mm (1.8 in.)	June 20 = 3 mm (0.12 in.)	16 days
Carrots 0.9 m (3ft.)	sandy loam 13 mm/10 cm (1.5 in./ft.)	117 mm (4.5 in.)	40	47 mm (1.8 in.)	July 30 = 6 mm (0.24 in.)	8 days

* Moisture available in the crop's root zone when the soil is at field capacity.

Soil moisture determination

Water applied to a field, whether by irrigation or precipitation, will do a number of things. Excess or free water will penetrate into the soil and gradually move downwards out of the surface root zone. Some moisture will evaporate from the soil surface. Plants will also take up moisture, depleting the total amount in the soil.

To be most efficient when scheduling irrigation, you need to know how much water is being lost from the soil, whether through evaporation or transpiration or through movement out of the main root zone. It is also important to determine the amount of moisture in the deeper root zones, which can be used by mature crops with larger root systems.

Producers can use a range of tools to determine the amount of available moisture in the soil and to schedule irrigation accordingly.

The most basic method of soil moisture determination is "hand-feel." By understanding how a particular soil texture feels at a specific soil moisture content, an experienced producer can accurately estimate the soil moisture content of a soil, and determine where moisture is located in a soil profile. Then, with knowledge of the crop stage and its average water usage, producers can make irrigation decisions. It is important to have a representative soil sample from the entire effective root zone. (For more information on the hand-feel method, see the Appendix)

Other technologies for tracking soil moisture content include tensiometers, gypsum block probes, neutron probes, time domain reflectometry (TDR) units, etc. Each of these tools measures soil moisture in a different way. Some tools, such as the neutron probe, require special training and equipment and would not be available or useful for the average person. Tensiometers and gypsum block sensors are easily used by producers, without undue expense. TDR units fall somewhere in the middle and are technology that field scouts use.

Tensiometers

A tensiometer consists of a tube with a porous cap at one end and a meter at the other end that measures changes in how tightly water is being held to soil particles. The tube is filled with a liquid and is inserted at a specific soil depth (depending on what portion of the root zone you want to measure). Once the system equilibrates, the meter will measure the changes in the soil moisture content. When the meter reaches a certain soil moisture tension, irrigation is required.

Tensiometers are limited in the level of soil moisture deficit they can measure (-80 centibars (cbar)), but their range is sufficient for vegetable crops. Tensiometers require a period of equilibration, as well as continuous maintenance.

A tensiometer only measures soil moisture in one location and one depth. Therefore, in many instances, more than one tensiometer will be placed in the field for the duration of the season, often at varying depths, allowing the grower to track soil moisture content at various points in the rooting zone.

Readings can be taken in place, or the tensiometers can be connected to remote recorders, which can be linked to computer-controlled irrigation systems.

Gypsum block probes

A gypsum block probe consists of a porous block (often gypsum) with embedded wires that run from the block back to the soil surface. The gypsum block is implanted in the soil to the desired depth in the root zone. Like a plant root, the gypsum block absorbs water from the surrounding soil.

When an electrical current is applied to the block through the wires, the flow of current across the block will be proportional to the moisture content of the block and the surrounding soil. This current flow is measured using a specially calibrated meter designed to convert the current flow to a corresponding estimation of soil water potential/content. Irrigation can then be scheduled based on the soil moisture content.

A gypsum block probe can only measure soil moisture at a single location and soil depth. In many cases, more than one block will be placed in the field for the duration of the season, often at varying depths in the rooting zone, to track moisture at various locations and depths.

Calibration is required before use, but less maintenance is required than with tensiometers. The capacity of gypsum blocks to measure soil moisture deficits is adequate for vegetable crops (-120 cbars). Gypsum blocks can be read in place or can be connected to remote recorders, which can be linked to computer-controlled irrigation systems.

Neutron probes and time domain reflectometry (TDR) units

Neutron probes and TDR units require no calibration period and can measure many locations and depths in a field with a single unit. However, neutron probes are limited to locations in a field where access tubes have been installed. TDR units can be used simply by inserting the instrument into the soil at the desired depth and location, and reading the soil moisture content.

Both systems tend to be more robust than either tensiometers or gypsum blocks, but they are considerably more expensive. The use of neutron probes requires special training, equipment and permits, as the technology is based around some dangerous materials. It would not likely be considered practical for producers.

Growing season extension

One of the perennial challenges facing vegetable producers on the Canadian Prairies is the relatively short growing season. A short growing season has the potential to reduce both yields and quality, especially for warm-season crops like peppers, tomatoes and melons.

By implementing various techniques and practices to extend the growing season, producers may achieve the following benefits:

- ensure that crops mature, while also increasing yields
- grow different crops and better quality varieties
- allow crops to reach peak ripeness and quality
- produce crops outside the typical growing season
  - accelerate maturation and ripening for earlier markets
  - reach late markets due to frost protection through the fall
- reduce the risk of crop failure due to adverse growing conditions

A number of basic practices are available to speed crop development and enhance productivity in a short, cool growing season. To start with, carefully select adapted crops and cultivars, and ensure that plants are supplied with adequate nutrients and water and are free from weed, insect and disease problems.

Some crops require special conditions to grow optimally under a typical growing season on the Canadian Prairies. Warm-season crops need warm soil to germinate and are sensitive to frost and chilling injury from seeding through harvest and eventual consumption.

To satisfactorily grow warm-season crops in regions with a cool, short growing season, a number of techniques can be used to both enhance the growing conditions and to extend the growing season:

- transplants
- raised beds
- soil mulches
- row and crop covers
- high tunnels
- combinations of these techniques

Transplants

Transplants are typically grown in a greenhouse and then transplanted into the field. The use of transplants can advance production by 2 to 4 weeks. Transplants can be used for almost all warm-season crops but can also be used to speed maturity of cool-season crops. To gain the greatest advantage from using transplants, ensure that plants are properly acclimated prior to transplanting and are treated carefully during the transplanting process.

For more information on the benefits of transplanting, the use of transplants and transplant establishment, see the chapter on Transplant Production or the Transplanting section earlier in this chapter.

Raised beds

Raised beds allow a vegetable crop to tolerate excess moisture conditions better than if the crop were planted on the flat.

Raised beds can be made in the fall or spring. If the beds are created in the fall, then the producer can start seeding or transplanting earlier in the spring.

Before creating raised beds, producers must properly prepare the soil with deep, intermediate and shallow tillage. A common practice is to do one deep tillage operation (at least 20 cm (10 in.) deep) and two or more medium or shallow tillage operations (usually rotovating), with the operations being performed perpendicular to each other.

Then, the bed can be shaped. Beds typically range from 8 to 15 cm (4 to 6 in.) in height. Plastic mulch and/or drip irrigation tape can be laid over the bed, if desired.

Soil mulches

The purpose of applying mulch to the soil surface is to alter the conditions to improve or optimize crop growth. Mulches may be made of plastic, organic matter (e.g. wood chips, bark, straw, paper, etc.) or other types of temporary material.

Table 22 lists the effects of various types of mulches. Most mulches conserve soil moisture. Many types also affect soil temperature. For example, black and clear plastic mulches increase soil temperatures, with clear mulches heating the soil more than black mulches. White, reflective plastic mulches and organic mulches keep the soil cooler than normal.

All mulches except clear will slow or prevent weed growth. When using clear mulch, a herbicide may be used to control weeds under the plastic, although research has shown that weed growth under clear mulch usually has relatively little effect on crop yield.

Wavelength-selective mulches (infrared transmissible (IRT) mulches, which are green or brown) are designed to provide soil warming similar to clear mulches while also preventing weeds.

Table 22. Comparison of different types of soil mulches		
Mulch type	**Advantages**	**Disadvantages**
Clear plastic	Rapid heating; soil temperature increased by several degrees; moisture conservation	Weed growth; rapid heat loss (no heat trapping)
Black plastic	No weed growth; inexpensive; soil temperature increased somewhat; moisture conservation	Less heating of soil than with clear plastic (some transfer of heat with contact with soil)
Wavelength-selective plastic/infrared transmissible	No weed growth; some soil heating (increased by 1-2°C; 1.8-3.5°F); moisture conservation	More expensive
Coloured plastic (red, yellow, blue, etc.)	Similar to black; some reflection of different wavelengths of light may improve yield and ripening; moisture conservation	More costly; unproven benefits
Biodegradable plastic (different colours and characteristics)	Early benefits similar to other plastic mulches; barrier not in place permanently; no need for removal; moisture conservation	May not fully break down in soil; benefits are lost as the mulch begins to break down
Compostable plastic (different colours and characteristics)	Early benefits similar to other plastic mulches; no removal requirement; compatible with organic production systems; moisture conservation	Lose benefits of mulch at a variable rate
Organic (straw, paper, wood chips, etc.)	Soil cooling; moisture conservation	Slow to warm; can tie up nutrients as breaks down; may harbour rodents

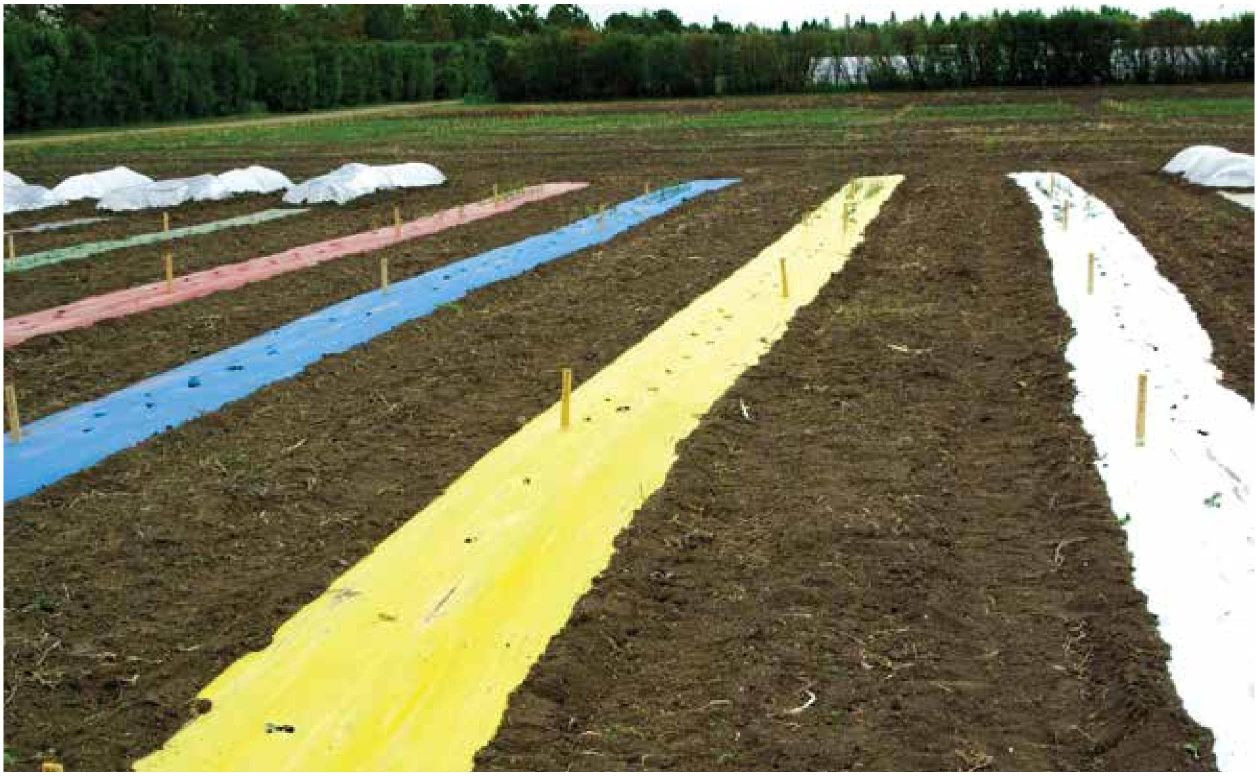
Red, blue and yellow mulches are also available. They are often suggested as useful in enhancing the growth and ripening of specific crops (e.g. tomatoes) due to their ability to reflect specific wavelengths of light back into the crop canopy or onto developing fruit. However, the benefits of growing a crop on a specific colour of mulch appear inconsistent and are rarely sufficient to offset the substantially higher costs of the coloured mulches.

Plastic mulches

The typical plastic soil mulch is 2 mm (0.08 in.) thick and 120 cm (48 in.) wide and comes in rolls of 300 m (about 1,000 ft.) or more in length. Thicker mulches are more durable, but also more expensive.

Plastic mulches are best laid with a commercial mulch applicator. It is critical that the soil be smooth, moist and free from lumps and crop debris before laying the mulch. A well prepared soil ensures a tight union between the plastic and soil. This tight union promotes the efficient transfer of heat to the soil. About 15 cm (6 in.) of the edges of the plastic should be buried into the soil to prevent wind from picking up the mulch.

Drip irrigation lines are typically installed under the mulch at the time of mulch application. While it is possible to use overhead irrigation to provide moisture to a mulched crop, drip lines are more efficient and effective.



Coloured plastic mulch comparison research
Photo: Jackie Bantle

Mechanized plastic mulch layer
Photo: Robert Spencer

Raised and mulched beds with different colours of mulch
Photo: Robert Spencer

Seeds or transplants are set into holes cut in the mulch. Machinery designed to seed or transplant through plastic mulches is widely available.

The purchase and installation of a plastic mulch as well as the removal and disposal of the mulch at the end of the growing season represent additional production costs. As a cost-saving measure, it may be possible to leave the mulch in place and grow a second crop on it, either within a single growing season or in the following season. However, this practice involves challenges with both fertility and pest management.

Biodegradable plastic mulches offer a potential solution to the problem of mulch removal and disposal at the end of the growing season. These mulches are designed to last through a single growing season, and then, the biopolymers used to form the mulch break down, allowing them to be incorporated into the soil as an amendment to the soil organic matter.

The durability of biodegradable mulches is influenced by exposure to ultraviolet light, temperature and moisture levels. Consequently, their performance may vary from season to season.

Compostable plastic mulches are comprised entirely of materials that will break down completely in soil over time, as opposed to biodegradable mulches, which may break into pieces, leaving fragments of mulch that take a long time to break down. Compostable plastics are often made from natural materials, such as corn starches, etc.

Organic mulches

Organic mulches do not tend to contribute much toward growing season extension, although they may enhance the growth of cold-adapted crops, such as garlic, or in situations where soil moisture is a potentially limiting factor. Examples of common organic mulches include straw, paper, wood chips/shavings, bark, etc.

Organic mulches do the following:

- cool the soil, which is mostly counter-productive for Prairie vegetable production, except for a few cold-adapted crops, such as garlic
- generally require more labour to apply
- often introduce weed seeds to the field and do not typically control weeds unless applied as an extremely thick layer
- offer shelter for crop pests such as slugs, cutworms, earwigs and rodents
- may contain toxicants like herbicide residues or natural germination inhibitors
- tend to keep the crop clean by forming a barrier between produce and the soil surface
- are easy to dispose of by incorporation into the soil at the season end
  - incorporating an organic mulch may increase soil organic matter content but may also bind available nitrogen as these mulches tend to have a high C:N (carbon:nitrogen) ratio
- allow water (irrigation or rainfall) to pass through freely
- increase soil moisture retention through cooling and reduced evaporation

Microclimate modification

Microclimate modification refers to the modification of the climate in the immediate area around the individual plants. Microclimate modification can increase crop growth rates significantly, mainly by protecting the plant from wind damage and by increasing air temperature.

Microclimate modification may involve using individual plant covers or covering the entire crop. Correct timing of removal when using crop covers is critical. Overheating under the covers can harm the crop. Many crops require the presence of pollinating insects, which can be inadvertently excluded by covers.

Plant covers

Historically, many different devices have been used to cover growing plants in an attempt to improve the growing conditions. Early devices included the “cloche” (French for “bell”), which, in its earliest forms, consisted of an individual glass container or dome placed over each plant.

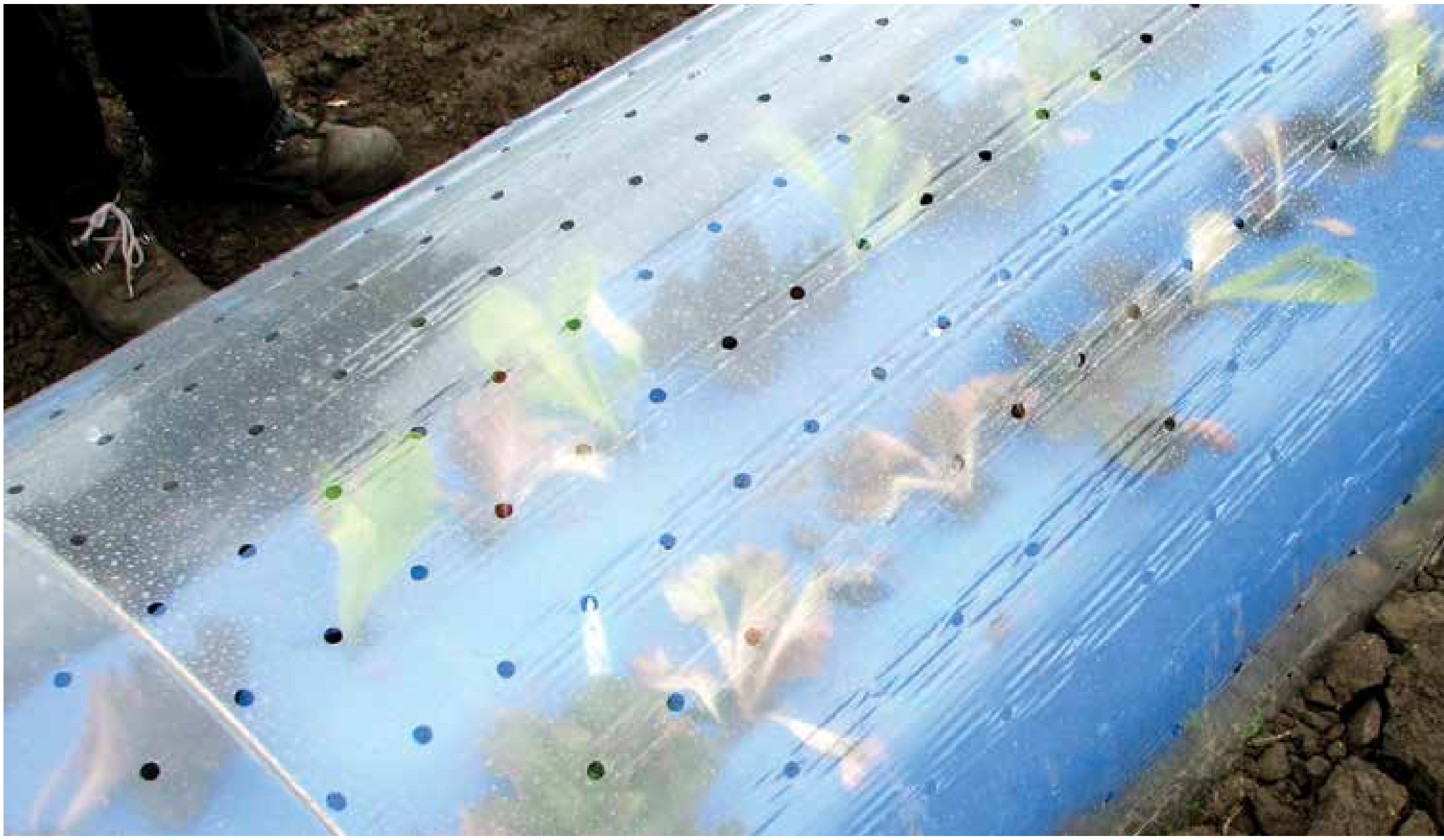
The hot cap is a variation on this design and has been used throughout history, with modern versions consisting of covers made of plastic, fabric or some other material. The use of individual plant covers is feasible for a small number of individual plants. However, on a large, commercial scale, these individual covers would not be economically feasible.

Row covers

Row crops, particularly those planted into plastic mulch, lend themselves to being covered en masse, in their rows. Row covers are more efficient and cost-effective than covering individual plants.

Covering rows of a vegetable crop with a transparent material like perforated clear polyethylene or woven polyester fabric produces a warm, sheltered greenhouse-like environment. This sheltered environment can dramatically enhance the growth of warm-season crops during cool weather, especially when the covers are used in combination with soil mulches. The row covers may increase daytime temperatures in the vicinity of the crop by as much as 10°C (50°F). However, the covers provide little frost protection.

Row covers (a.k.a. low or mini tunnels) are usually supported above the crop by wire hoops (180-cm (6-ft.) pieces of no. 9 galvanized wire), which are positioned about 1 m (3.3 ft.) apart to create a low or mini tunnel. The spun-woven row cover materials may be used on low-growing vine crops without support by hoops, but this practice is not recommended for upright crops like tomato and pepper where the terminal growing point may be damaged by direct contact with the cover.



Perforated row cover over lettuce seedlings
Photo: Robert Spencer

Machines are available that will insert the hoops into the soil, lay the row cover material over the hoops and then bury the edges of the row cover with soil. Otherwise, these steps may be done by hand.

The crop is established either by seeding or transplanting before the application of the row covers. While it may be possible to meet the moisture needs of a covered crop with normal sprinkler irrigation, drip irrigation is more effective and efficient.

Although all warm-season crops, and even some early planted cool-season crops, may benefit from the use of row covers, care must be taken to remove the covers before they start to interfere with the growth and development of the crop.

For example, while row covers may enhance the early growth of tomatoes, if they are left over the crop too long, the excessively high temperatures created by the covers may delay fruit set and cause plant injury. Row covers also interfere with the activity of insect pollinators and must be removed when flowering begins.

The plants inside a row cover will be growing in a modified greenhouse atmosphere. Thus, removal of the tunnel should be done on a cool, cloudy day to reduce plant shock. Slitting the row cover down the middle at least 2 days before removal helps to introduce the covered plants to the outdoor environment gradually, after which the row cover can be completely removed.

Crop or field covers

Field or crop covers are intended to protect many rows of the crop with a single piece of material. The woven material used in field covers is similar to that used for row covers, but a heavier material

Low tunnels installed in a field
Photo: University of Saskatchewan

is typically preferred, so the field cover can be used over several seasons. Field covers are wide enough to cover several rows at a time (up to 20 m (66 ft.) wide) and come in lengths up to 300 m (about 1,000 ft.).

The field cover's edges must be thoroughly and securely anchored; otherwise, the cover may lift in the wind. Burying the edges with soil is the simplest approach. However, weighing down the edges with easily removed heavy objects such as sandbags or pipes makes it easier to lift the covers to inspect the crop or carry out any management activities.

Field covers are typically allowed to rest directly on the plants without the support of hoops. However, this practice is not recommended for young plants or for upright crops like tomato and pepper where the terminal growing point may be damaged by direct contact with the cover.

In addition to providing a warm, sheltered environment for the developing crop, field covers may also screen the crop from attack by air-borne insect pests such as flea beetles, grasshoppers and loopers. As the field covers are large enough to cover mature plants, they may be used to extend the growing season in the fall, as well as in the spring. Heavier field cover materials provide a greater degree of frost protection but are more costly.

The spun-woven fabrics used to make field covers will allow rain to pass through onto the crop. Sprinkler irrigation may be used with crop covers. The use of drip irrigation and plastic mulches is highly compatible and efficient with this technology. Since field covers are not completely sealed to the ground, pollinator insects can also to enter.

High tunnels

High tunnels are basically low-tech greenhouses, as they do not have electricity or supplemental heat or any other form of automated environmental control system. High tunnels typically consist of a single layer of 6 mil clear polyethylene stretched over metal or plastic arches to form a Quonset shape. A portion of the side walls of the tunnels are designed to be manually raised or lowered to provide some control over temperatures in the high tunnels.

Spun-woven floating row cover over multiple rows provides protection in spring
Photo: Robert Spencer

Broccoli growing inside high tunnel
Photo: Jackie Bantle

The tunnels may be purchased or constructed in a variety of heights, widths and lengths, depending on the needs of the grower. A typical size is about 4 m (13 ft.) wide, 3 m (9.8 ft.) tall and 30 m (98 ft.) long. High tunnels may be free-standing units or may be linked at the sides to create a larger growing area. The end walls of the high tunnels are easily removed to allow access by tractors or other equipment.

Drip irrigation is typically used in high tunnels. Plastic mulches can be used within high tunnels to further enhance crop growth.

The warm, sheltered conditions inside the high tunnels are of greatest use in accelerating the development of warm-season crops. High tunnels provide little frost protection and are, therefore, of limited value for extending the growing season.

In mid-summer, temperatures in the high tunnels may also become excessively hot, even with the sides of the tunnels fully rolled up. This feature limits their usefulness for growing cool-season crops and may even interfere with some heat-sensitive growth stages in crops like tomato and pepper. Some pests, such as spider mites, may thrive in the unique environment created by the high tunnel and may require special management.

The crops in a high tunnel are typically grown directly in the soil, rather than in some sort of raised bed. As the high tunnels may be left in one spot for a number of years, there is an associated risk of either damaging the soil structure through repeated intensive cropping or for pathogens or insect pests to build up within the tunnels.

Equipment

A wide range of types of mulch layers is available from specialty horticulture equipment dealers. Most of these units are three-point hitch mounted. Modifications are available to improve the control over row straightness and the machine's ability to "hug" the soil while applying the mulch.

The three basic functions of a mulch layer are as follows:

1) shape the soil into a slightly raised bed, which ensures close contact between the soil and the mulch
2) lay the mulch down tightly
3) securely bury the edges of the mulch

Many mulch layers have the capacity to lay drip irrigation while applying the mulch. Some units also have enhanced bed shaping capabilities.

Other equipment is available for applying row covers (including the cover and the hoops).

All these pieces of equipment represent an additional cost to your operation.

Harvest and post-harvest management

Vegetable crop quality is directly related to harvest timing and post-harvest handling. Improper harvesting and handling can negate the effort expended during the growing season.

Harvest timing generally depends on crop maturity, which can be recognized by colour change, skin set, size and many other factors. Harvesting at the right stage of maturity is often difficult but is critical to achieving good final quality.

Whether harvesting is done by machine or by hand, take care to avoid damage to the commodity. Bruising can cause discolouration or decay and may reduce the grade of the product. All types of injury open the door for the development of post-harvest rots and decays.

Vegetable quality, in terms of flavour, colour and size, generally improves as a product reaches maturity and then declines after a peak of maturity is reached. You should be able to judge optimum maturity for all the products you produce.

Deterioration in quality continues during storage. How products are handled post-harvest will determine the rate and eventual extent of the deterioration. Careful handling and storage can significantly extend the post-harvest lifespan of many crops, resulting in improved market access, prices and returns. Each vegetable crop differs in how it should be handled and stored in terms of temperature, humidity, etc. Adhere to storage guidelines to maintain quality.

Harvest management

Several factors influence when harvest should take place, and these same factors also affect eventual produce quality and returns to the producer. Sometimes, depending on these factors, adjustments to harvest and post-harvest practices need to take place.

Maturity

All crops should be harvested at the correct stage of crop development, which is, in many cases, as close to fully mature as possible. This practice maximizes yield as well as produce quality. Harvesting an immature or overripe product will result in a harvested crop that does not respond the same as a crop harvested at the proper time and will, therefore, have to be handled differently.

A certain amount of variability in optimum maturity at harvest exists between and within crops. The correct harvest stage depends on what market the product is destined for and is very specific to each crop. For example, harvesting snow peas at the same stage as fresh peas would result in an unmarketable product. Snow peas are best harvested when pods are tender and seeds are undeveloped. Harvesting at a later stage will result in tough pods and poor quality.

In some cases, crops are not harvested when fully ripe, but rather when they have reached a certain stage of physiological development or "physiological maturity." This term is used to describe when a crop has reached the point beyond which the only changes are increases in sugars or other ripening activities, such as softening.

For example, tomatoes are physiologically mature when the first indication of colour change occurs,

Stages of tomato maturity and "breaker stage"
Photo: David Rhodes, Purdue University

often referred to as the "breaker" stage. After this point, the tomato will continue to increase in sugar content and will turn colour completely. For some crops, until a product is physiologically mature, it will not ripen properly off of the plant.

Temperature

Temperature influences the rate of crop development up to harvest. Temperatures at harvest have a significant effect on post-harvest handling, and temperatures during subsequent storage affect post-harvest quality.

For crops like carrots and beets, it is best to harvest in cooler conditions, as this practice reduces the amount of cooling required after harvest. For crops such as onions, warm, dry conditions are preferred at harvest, which will allow for drying in the field.

Other crops, such as potatoes, should be harvested at temperatures between 7 and 15°C (45 and 59°F). Harvesting potatoes when temperatures are warmer will result in an increased incidence of tubers with blackspot bruising, while harvesting at colder temperatures increases the risk of shatter bruising.

Sometimes, produce will be frozen in the field due to rapid changes in temperature. It is generally best to harvest frozen crops after thawing has occurred. Frozen produce will usually not store properly and is prone to storage rots. Frost-damaged produce should be heavily graded to remove any damaged or unmarketable product.

Moisture

Vegetables are sold by weight, and they are made up of over 80 per cent water on average. Therefore, you will need to optimize and maintain water content through the entire harvest and post-harvest management period so as to maximize profit.

Provide crops with sufficient water before harvest, but do not overwater because some diseases increase when crops are harvested in wet conditions, such as some diseases in potato. Watering can also encourage continued growth when crops should be maturing off.

Frost damage on bean; note discolouration and shrivelling of leaves
Photo: Robert Spencer

Produce damage

Make every effort to minimize damage during harvest and post-harvest handling operations. Damage can include wounds, bruises, scuffs, scratches, etc. Wounds represent holes in the armour of the crop where pathogens can enter. Some pathogens will infect even when the damage is only a spot of weakened tissue, such as a bruise.

The best way to reduce damage is to minimize handling. This approach might include reviewing your harvest and post-harvest process and eliminating unnecessary steps or improving the efficiency or effect of specific steps. Alternatively, specialized machinery can be used to reduce handling or to improve handling processes.

When using mechanical harvesting, properly calibrate and set up equipment before the start of harvesting. Replace worn or broken parts to ensure produce moves correctly through equipment. Operators of harvesters should be well trained.

When hand harvesting is used (which is often the case for many vegetable crops on the Prairies), harvesters must be trained to recognize differences in maturity, avoid poor quality produce and carefully handle all produce.

Produce should move from the field into the post-harvest system as quickly as possible.

Some crops benefit from a period of pre-harvest preparation to reduce bruising, scuffing or wounding or to ensure they enter storage in high quality. For example, potatoes should be top-killed about 2 weeks before harvest, to allow skin set to occur. Other crops, such as onions, may be lifted and windrowed to allow toughening and tightening of the skin.

In all cases, only quality produce should be allowed to enter the post-harvest system. It is virtually impossible for crops to improve in quality after harvest.

Equipment

Many different types of equipment are used for harvesting, ranging from simple hand tools to complex self-propelled or tractor-driven machines. Some crops are harvested using a number of steps and machines. Others are cut and packaged directly in the field.

As with all equipment, consider the overall cost to purchase and operate harvesters, balanced against the time saved.

Post-harvest handling

Once produce has been separated from the plant, some degree of post-harvest handling must take place. The main objective of post-harvest handling is to maintain a saleable product for as long as possible.

Depending on the crop, the post-harvest process may consist of a number of steps. At all stages, take care to prevent additional damage or deterioration of quality. Most post-harvest handling should be done as quickly as possible and at as cold a temperature as possible, as the lifespan of produce can be quite short.

If possible, only harvest the amount of produce you can reasonably handle and market at any one time. Consider this amount when creating crop plans before planting.

Cooling

All vegetable crops continue to be physiologically active, living and breathing (respiring) after they are removed from the plant at harvest. During storage and handling, vegetables continue to ripen, age and deteriorate. Generally, the rate of respiration, aging and deterioration will decrease as the temperature of the product decreases. Some crops respire more quickly than others, resulting in a shorter post-harvest lifespan.

The first goal of post-harvest handling is to quickly cool the product from field temperatures to the desired storage temperature. Harvesting during cooler weather will reduce the amount of field heat that must be removed after harvest.

Methods of removing field heat can include the use of various types of coolers or cold chambers, application of water (misting) or ice (hydro-cooling) or other methods. Methods differ in their rate of cooling, cost and suitability for specific crops. Try to find a balance between these different factors when selecting a cooling method.

Sorting and grading

Despite the care taken during harvest, not all harvested produce will be of marketable quality. If some sorting and grading can be done in the field, this practice will reduce the costs of further handling. However, if grading in the field slows the harvest operation, the overall quality of the crop can be compromised.

Once the crop has been harvested, separate marketable from unmarketable product, separate different sizes and grades, and improve produce quality by some trimming or other activities.

Trimming

Trimming is done to remove damaged parts from otherwise marketable product or to trim off excess or unnecessary materials, such as roots, leaves, crowns, etc. Some crops, such as carrots or parsnips, require their leaves to be removed before washing and storage, as the leaves break down more quickly than the roots, increasing the incidence of rot and decay.

Other crops, such as celery, head lettuce or cole crops (e.g. cabbage, cauliflower), benefit from

Potatoes on grading line
Photo: Tom Gonsalves

Proper washing is a critical part of on-farm food safety activities and must include considerations for disinfection of the water and washing equipment. Ensure that all washing equipment is functioning properly and that water is changed and treated with an approved disinfectant (e.g. chlorine) regularly. The potential for the buildup of pathogens and subsequent contamination of clean produce is significant.

Some crops are not washed immediately after harvest. For example, potatoes store better dirty and are only washed before they are packaged for sale.

the careful removal of a few, select outer leaves or stalks, in addition to any damaged leaves. Trimming should occur before packaging for sale (typically post-storage for stored crops).

Sizing

Many vegetable crops are sold in different size grades. By sorting crops into similar sizes, producers can easily handle the various grades and can price accordingly. Some sizes or grades can be sold for a premium, such as “creamer” or “baby” potatoes. In some cases, over- or undersized produce is unmarketable and must be discarded.

Grading for size can be accomplished by hand or machine. Simple grading charts and templates are available. By training staff and using appropriate, well set-up machinery, you can accomplish your grading quickly and efficiently.

Washing

Most vegetables are washed with potable water at least once before sale. Some types of vegetables require multiple washings and rinses to remove dirt and debris as well as to prepare the produce for sale. All wash operations must be gentle, yet thorough and effective.

Curing and wound healing

Some crops benefit from a period of warm, dry conditions before long-term cold storage. This treatment is referred to as curing and/or wound healing. This period allows produce to heal and for skins to tighten, preventing future water loss, reducing the risk of infection by pathogens (via wounds) and improving overall quality.

For example, keeping potatoes at 15°C (59°F) and a relative humidity of over 80 per cent for 2 to 3 weeks immediately after harvest allows wounds, scuffs and scrapes on the tubers to heal and wound tissues to develop.

Onions can be cured or dried in the field, if conditions are suitable, but are most often cured indoors. Onions are cured with ventilation for 7 days at 32 to 35°C (90 to 95°F), and then temperatures are lowered to 26°C (79°F) until the 10- to 14-day curing period is completed. This curing process tightens up the outer layers of skin, protecting the onion from pathogens and moisture loss. Following the curing period, storage temperatures are gradually dropped by 1 to 2°C (1.8 to 3.6°F) per day to appropriate levels for long-term storage.

Vegetable washing line equipment
Photo: Robert Spencer

Packaging

Some highly perishable vegetable crops (e.g. leafy greens, asparagus, beans, peas, cucumbers, etc.) cannot undergo any significant storage time.

In many cases, these crops are packaged shortly after harvest, either in the field or after a short period of cooling, washing, grading or other post-harvest activities. At this time, produce would be packaged in the final sample size for sale.

Packaging materials might be clear bags, clam shells or other containers. Packaging should be appropriate for the type of crop and point of sale. Packaging materials should also conform to any applicable regulations.

Equipment

Many different types of equipment are available to save time and labour in post-harvest processes. These include graders, conveyor belt systems, washing lines, trimming machines, brushers, driers, polishers, bagging machines, etc. Consider the overall cost and benefit of each piece of equipment before buying.

Storage and storage management

Many vegetables can be satisfactorily stored for a relatively long term in the proper storage environment. Providing suitable storage conditions is the key to successful storage.

Consider the following important categories during the storage design and planning process:

- Specific storage requirements – for the different vegetable types and varieties
- Environmental control – for temperature, humidity, ventilation and related control systems and management

- Functional design – to provide sufficient space to store anticipated volumes of the crop, as well as space for equipment and facilities for convenient handling, grading and marketing of produce
- Structural design considerations – to ensure the storage building is designed for climatic loads (wind and snow loads), product loads (the force of piled vegetables), earth pressure and equipment loads – storage must be very well insulated with a properly sealed, well located, good quality vapour barrier

This section summarizes storage requirements for typical market garden or small-scale commercial production. Large, commercial storages will require more specialized design of the structure, cooling capacity and related mechanical equipment.

Factors influencing storage lifespan

Each type of vegetable has specific requirements to achieve maximum storability. By providing ideal storage conditions, respiration, transpiration rates and metabolic processes can be lowered to prolong the product's lifespan. The main factors that influence the storage life of a vegetable crop are temperature and humidity.

Temperature

Temperature has a direct influence on the rates of respiration and metabolic activity of harvested produce, which affect deterioration, aging, ripening, water loss, senescence (aging), etc. Temperature also influences the rate of development of spoilage pathogens in storage.

In general, the lower the temperature in storage, the slower the rate of deterioration and respiration of stored produce. Cool-season crops, such as cabbages, have different tolerances for minimum storage temperatures than warm-season crops, like beans and tomatoes. If temperatures are too low, warm-season crops can experience chilling injury, which disrupts normal metabolic processes resulting in poor quality and reduced post-harvest lifespan.

All crops may experience freezing injury if temperatures drop to freezing or lower. Damage from freezing or chilling becomes apparent when produce is returned to warmer conditions.

Humidity

A harvested vegetable continues to lose water by transpiration throughout the storage period. The rate of loss relates directly to the relative moisture content of the surrounding air. Drier air results in an increased flow of water from the vegetable, producing wilted or softened produce.

Producers can increase the relative humidity of the storage by using a humidifier, by wetting the floors and by misting or wetting produce. Managing the relative humidity is linked to temperature management of the storage, as temperature influences relative humidity. For instance, lower temperatures result in increased relative humidity.

Other treatments, such as waxing or wrapping, can be applied to certain vegetables (e.g. rutabagas, turnips, etc.) to create a vapour barrier around the individual produce to reduce moisture loss.

Other factors

Some crops are highly sensitive to exposure to ethylene gas, resulting in alteration and deterioration in quality. Certain crops naturally produce ethylene during the ripening process. Rotting or damaged produce can also emit ethylene. Differences in the production of and sensitivity to ethylene can limit the potential to store different vegetables in common storages.

Storage conditions for vegetables

Proper storage conditions must be met to maximize the post-harvest lifespan of harvested vegetables. Table 23 summarizes these requirements. The notes following Table 23 explain some of the more detailed aspects of storage management.

Only crops requiring similar conditions will store well together. Some groups of vegetables can tolerate a compromise of conditions without excessive sacrifice of storage lifespan or quality.

For example, both potatoes and root vegetables require high humidity; however, potatoes should not be stored cooler than 5°C (41°F), while root vegetables store best at 0°C (32°F). Therefore, it is best to use separate storage rooms for each. However, where these crops must be stored together, store everything at 4 to 5°C (39 to 41°F) and high humidity. This atmosphere results in somewhat shorter storage life (though good for 3 months) for root crops, without causing undue damage (sweetening) to the potatoes.

Here are general recommendations for the post-harvest handling and storage of all vegetables:

- Harvest only mature crops.
- Grow varieties that have a long storage lifespan.
- Remove all diseased or damaged produce before storing.
- Handle produce carefully to avoid damage.
- Pre-cool the cold storage.
- Try to harvest in cool conditions, such as early morning.
- Wet the floors of the storage ahead of time (particularly earth floors).
- If frost-damaged, diseased or immature crops must be stored, try to store them separately and market them early.

Table 23. Storage requirements for vegetables

Produce[1]	General storage type	Bulk density[6]		Pile depth		Temperature		Relative humidity	Approx. storage period
		(kg/m³)	(lb./ft.³)	(m)	(ft.)	(°C)	(°F)	(%)	
Asparagus	Cold & humid			n/a	n/a	0 - 2	32 - 35	95 - 100	2 - 3 weeks
Beans[7] (green, snap)	Cool & humid			n/a	n/a	4 - 7	40 - 45	95	7 - 10 days
Beets (bunched)	Cold & humid			n/a	n/a	0	32	98 - 100	10 - 14 days
Beets (topped)	Cold & humid	700	44	3 - 4	10 - 14	0	32	98 - 100	4 - 6 months
Broccoli	Cold & humid			n/a	n/a	0	32	95 - 100	10 - 14 days
Brussels sprouts	Cold & humid			n/a	n/a	0	32	95 - 100	3 - 5 weeks
Cabbages[4]	Cold & humid	500	31	2 - 3	6 - 10	0	32	98 - 100	2 - 6 months
Carrots	Cold & humid	550	34	3 - 4	10 - 14	0	32	98 - 100	4 - 6 months
Cauliflower	Cold & humid			n/a	n/a	0	32	95 - 98	3 - 4 weeks
Celery	Cold & humid			n/a	n/a	0	32	98 - 100	2 - 3 months
Corn (sweet)	Cold & humid			n/a	n/a	0	32	95 - 98	5 - 8 days
Cucumbers[7]	Cool & humid			n/a	n/a	10 - 13	50 - 55	95	10 - 14 days

Table 23. Storage requirements for vegetables (continued)								
Produce[1]	General storage type	Bulk density[6]		Pile depth		Temperature		Relative humidity	Approx. storage period
		(kg/m³)	(lb./ft.³)	(m)	(ft.)	(°C)	(°F)	(%)	
Ethnic vegetables (bok choy, etc.)	Cold & humid			n/a	n/a	0 - 5	32 - 41	95 - 100	variable
Garlic	Cold & dry			n/a	n/a	0	32	65 - 70	6 - 7 months
Leafy greens	Cold & humid			n/a	n/a	0	32	95 - 100	10 - 14 days
Lettuce	Cold & humid			n/a	n/a	0	32	98 - 100	2 - 3 weeks
Melons (cantaloupes)	Cool & humid			n/a	n/a	0 - 5	32 - 41	95	5 - 14 days
Melons[7] (honeydew)	Cool & humid			n/a	n/a	7	45	90 - 95	3 weeks
Onions[3] (cured)	Cold & dry	650	41	2 - 3	6 - 10	0 - 3	32 - 37	70 - 75	4 - 8 months
Onions (green)	Cold & humid			n/a	n/a	0	32	95 - 100	3 - 4 weeks
Parsnips	Cold & humid	550	34	2.5 - 3.5	8 - 12	0	32	98 - 100	2 - 5 months
Peas	Cold & humid			n/a	n/a	0	32	95 - 98	1 - 2 weeks
Peppers (bell)[7]	Cool & humid			n/a	n/a	7 - 13	45 - 55	90 - 95	2 - 3 weeks
Potatoes[2] (processing)	Cool & humid	670	42	4 - 5	14 - 16	7 - 10	45 - 50	90 - 95	5 - 10 months
Potatoes[2] (seed)	Cool & humid	670	42	4 - 5	14 - 16	4 - 5	39 - 41	90 - 95	5 - 10 months
Potatoes[2] (table)	Cold & humid	670	42	4 - 5	14 - 16	5 - 6	41 - 43	90 - 95	5 - 10 months
Pumpkins[5,7]	Cool & dry	600	37	n/a	n/a	10 - 13	50 - 55	50 - 70	2 - 4 months
Radishes (spring)	Cold & humid			n/a	n/a	0	32	95 - 100	3 - 4 weeks
Radishes (winter)	Cold & humid			n/a	n/a	0	32	95 - 100	1 - 3 months
Rutabagas, turnips	Cold & humid	600	37	3 - 3.5	10 - 12	0	32	95 - 100	4 - 6 months
Spinach	Cold & humid			n/a	n/a	0	32	95 - 100	10 - 14 days

Table 23. Storage requirements for vegetables (continued)									
Produce[1]	**General storage type**	**Bulk density[6]**		**Pile depth**		**Temperature**		**Relative humidity**	**Approx. storage period**
		(kg/m³)	**(lb./ft.³)**	**(m)**	**(ft.)**	**(°C)**	**(°F)**	**(%)**	
Squash (summer)	Cool & humid			n/a	n/a	5 - 10	41 - 50	95	1 - 2 weeks
Squash[5,7] (winter)	Cool & dry	600	37	1 - 1.5	3 - 5	10 - 12	50 - 53	50 - 75	4 - 6 months
Tomatoes[7] (ripe)	Cool & humid			n/a	n/a	13 - 21	55 - 70	90 - 95	4 - 7 days

Notes:

1. Most produce, particularly cabbage and potato, reacts negatively to light and should be stored in dark conditions. Do not store vegetables and apples together because apples give off ethylene, which causes off-flavours in carrots, parsnips and other vegetables.
2. Potatoes are normally cured for 2 to 3 weeks at 10 to 15°C (50 to 59°F) and high relative humidity, and then cooled slowly to storage temperature. Potato storage conditions depend on the variety and anticipated use.
3. Onions are either field cured or cured in storage at 32 to 36°C (90 to 97°F) with high airflow prior to long-term storage.
4. Cabbage storage quality and duration are highly variety dependent.
5. Squash and pumpkins should be well ripened before storage; cure at 30°C (86°F) then, reduce temperature.
6. Bulk density varies by 5 to 10%; use as a guide for estimating storage size requirements (conversion: kg/m3 x 0.0625 = lb./ft.³).
7. Chilling-sensitive crop.

Storage planning and design

The size, type and layout of storage should be determined before planting the crop. There are a number of different types of storages, not all of which are compatible with all vegetable crops.

When planning your storage, consider the following aspects:

- varieties or types of produce being grown and which ones may be stored together
- expected duration of storage
- size and number of individual bins required
- storage layout for convenient loading, handling and marketing
- facilities, space and layout needed for other possible post-harvest activities such as:
  - receiving and rough grading at harvest before storing
  - washing, grading or packaging
- future expansion or modification requirements
- utilities and services required
- water supply and wastewater disposal

Storage size

Carefully determine the total storage volume as well as the size and number of bins required. Storages vary from small, short-term cold rooms, to large single rooms, to multiple-bin structures. Storage facilities with separate bins or rooms are more costly to build and operate, but provide the advantage of smaller batches for better control, lower risk of storage losses and more flexibility in bin management.

Marketing requirements, crop volumes, crop varieties and storage management also affect storage design. For example, a seed potato grower who needs to keep many different varieties separate or a vegetable producer who grows many different crops may need several bins, while a large commercial potato producer may find one or two bulk storage bins are adequate.

Bulk storage size requirements can be estimated from the bulk density of the stored commodity (see Table 23). It is best to plan storage capacity for above-average yield and future expansion or changes, such as an added grading room or loading shed or refrigeration system.

Palletized storage capacity is determined by laying out the required number of pallet bins in tiers and rows. Stacking height is often determined by the capacity of the stacking equipment; tiers four to six layers high are typical. Most pallet bins fit a 1.2-m x 1.2-m (48-in. x 48-in.) module. Therefore, the most efficient room size has inside dimensions equal to a certain number of rows plus 30 cm (12 in.) to allow for correct spacing.

Storage types and construction

Storages can be grouped into two general types: bulk storage and palletized storage. Storages can be further classified according to the produce type or whether they are refrigerated, air-cooled or controlled atmosphere. Considerations related to proper design and operation are similar for all storage sizes.

In general, most types of farm buildings can be used to create a vegetable storage, provided they are structurally adequate, well insulated and meet the functional needs. Environmental control and a good insulation system are the key elements to good storage. Many different types of storage designs are in common use.

Most storages require accurate control of temperature and relative humidity. Whether storages are made of wood frame, steel or concrete, high levels of insulation and moisture resistance are required. Vapour barriers must be thorough and effective. For the coldest Canadian climates, minimum insulation factors should be RSI 5.5 (R31) for walls and RSI 6.5 (R37) for ceilings.

Some other general principles to consider, whatever the construction type:

- Insulate foundations, preferably on the exterior.
- Pay particular attention to the thermal bridges or "cold spots" in normally good wall or roof systems that can cause serious condensation problems. Solid studs, steel purlins and beams, and discontinuous insulation at foundations or plates are typical problem areas.
- Ensure durability and ease of maintenance and sanitizing.
- Use only chromated copper arsenate (CCA)-treated woods for all sills and any wood that is to be covered with polyurethane insulation. Do not use volatile and "smelly" pentachlorophenol or creosote.

Treated wood is not permitted in the interior of a vegetable storage, either where vegetables may touch treated wood or where moisture may drip from treated wood onto the produce. This restriction is in line with On-Farm Food Safety (OFFS) guidelines.

Bulk storage

For bulk storage, the produce is simply bulk piled in room-size bins. Thus, the bin walls must be able to contain the pressure exerted by the pile. Ventilation of bulk storage is accomplished by blowing conditioned air through the pile of produce from a duct system placed under the pile.

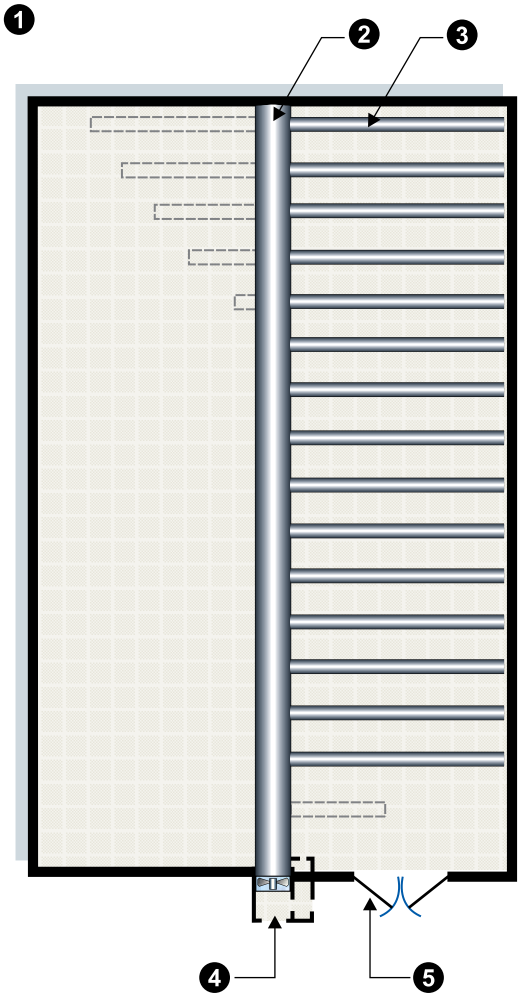
Professional engineering expertise is required for designing a bulk storage structure, so it can withstand climatic loads and the pressure exerted on the walls by the piled produce. The lateral forces and bending stress from the piled produce can be great, so do not underestimate structural requirements.

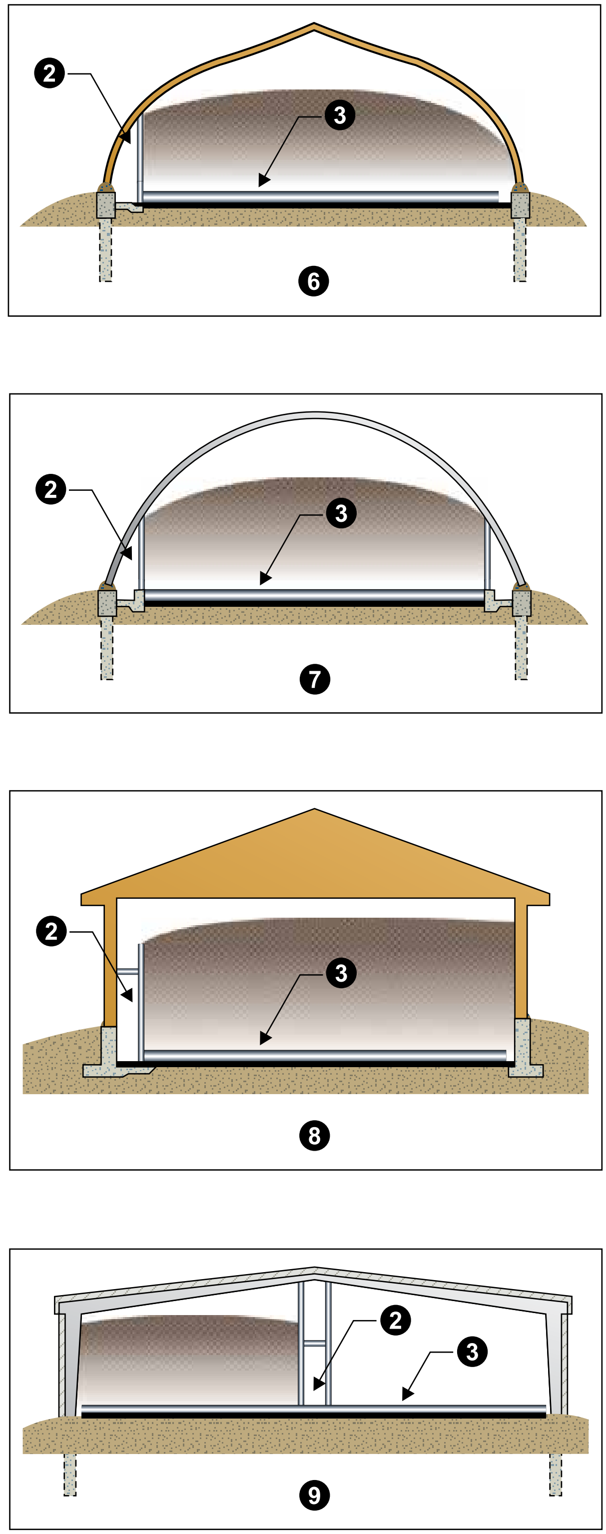
Pay particular attention to wall member strength, top and bottom wall connections, foundation side force and force on rafters due to wall pressure. For example, a 4.8-m (16-ft.) high potato pile exerts bottom and top plate forces of about 16.0 and 7.3 kilonewtons/m^2 (1,200 and 500 lb./$ft.^2$), respectively.

Bulk storage is generally less costly than storages where produce is contained in smaller units. It is best suited for crops that can be handled in bulk and piled fairly deeply, such as rutabagas, potatoes and onions. Other crops that may be bulk piled, but in shallower piles, include beets, carrots and parsnips.

Palletized storage

In palletized storages, the crop is placed in large boxes (pallet bins), which in turn are stacked in the storage room(s). The crop does not exert pressure on the walls; thus, the building only





1. Typical storage plan, single bin or double wide, as shown
2. Main air plenum
3. Branch ducts 3.0 m on centre
4. Fan room, air blending louvers, controls
5. Insulated storage doors
6. Laminated wood arch
7. Frameless steel arch
8. Wood stud frame
9. Steel frame, double wide shown (8 and 9 styles interchangeable)

Figure 4. Typical potato storage plan and alternate building types

needs to be designed to withstand climatic loads. The size of the individual pallet bins will vary, depending on the crop type and the amount of crop to be handled at any one time.

Pallet bin storage is generally used for crops that bruise easily or cannot be piled deeply, such as tomatoes, cabbages, parsnips, carrots and greenhouse crops. Palletized storage allows the storage of multiple varieties or types of crops, as well as crops from several growers. Palletized bins can be selectively marketed, and "problem" bins can be removed with less danger of widespread spoilage. It is the preferred storage type for warehouses and plants where produce turnover is frequent.

Pallet bins may be moved using various types of equipment. Many vegetables are sensitive to combustion fumes from fuelled vehicles. Therefore, consider using electric equipment in the storage.

Air of proper temperature and humidity is circulated between the rows of pallet bins. Pallet bins should be permeable enough to allow air to move in and around the stored produce.

Pallet-type storage buildings, like other buildings, should be professionally designed by a certified engineer for wind and snow loads. Consider designing the building for a change to bulk storage in the future, since pallet-type storages are not designed for bulk produce wall pressures. The highest floor loads are caused by fork-lift wheels.

Construction costs

The cost of building storages depends on many structural and environmental factors. In addition to the cost of storage space and related environmental controls, there are costs associated with constructing and equipping the grading and handling area.

A lower quality storage facility, such as a root cellar, can be built for a significantly lower initial cost than an aboveground structure. However, vegetable storage life (as it relates to the level of temperature and humidity control), overall building life, maintenance and ease of produce handling and operating procedures will be compromised in these simpler, lower cost storages.

Environmental control

Environmental control involves the management of temperature, humidity and airflow to provide optimal storage conditions. Environmental control is accomplished by circulating the correct amount of conditioned air through the produce pile or past the pallet bins in the storage.

Storages may be either air-cooled or refrigerated or both. Controlled atmosphere (CA) is a type of storage where the concentrations of oxygen and carbon dioxide are tightly controlled to further extend the storage period. CA was first developed for apple storages and is now used for vegetable crops like cabbages and sweet onions.

Air-cooled storage

For air-cooled storage, temperature is controlled by blending the correct amount of cold outdoor air into the ventilation system. This process requires outdoor temperatures to be below the storage temperature for all but short periods during most of the storage season.

Air-cooled storage is obviously best suited to crops like potatoes, carrots and beets, which are harvested in the cool weather of the fall and stored over the winter. Non-refrigerated storage will work for other vegetable crops, but storage life may be reduced if there is difficulty maintaining cold conditions.

Ventilation is the movement of conditioned air past or through the produce to remove heat, maintain uniform conditions and control humidity or condensation. Proper ventilation involves maintaining proper airflow rates and patterns by using a properly designed system of temperature controls, fans and ducts. Table 24 gives the recommended range of ventilation rates for a selection of vegetable crops.

Table 24. Ventilation rates for vegetables in bulk or palletized storage

Produce type	Ventilation rate			
	Bulk storage		Pallet bins*	
	(L/s-tonne)**	(cfm/ton)**	(L/s-tonne)	(cfm/ton)
Beets	10 - 12	19 - 23	15 - 20	29 - 38
Cabbages	10 - 12	19 - 23	15 - 20	29 - 38
Carrots	10 - 12	19 - 23	15 - 20	29 - 38
Onions (cold storage)	10 - 15	19 - 29	15 - 25	29 - 48
Onions (curing)	40 - 50	77 - 96	60 - 80	115 - 154
Parsnips	10 - 12	19 - 23	15 - 20	29 - 38
Potatoes (processing)	8 - 10	15 - 19	12 - 15	23 - 29
Potatoes (seed)	6 - 8	12 - 15	10 - 12	19 - 23
Potatoes (table)	7 - 9	13 - 17		
Pumpkins			15 - 20	29 - 38
Rutabagas, turnips	8 - 10	15 - 19	15 - 20	29 - 38
Squash			15 - 20	29 - 38

* Ventilation rate for palletized storage is closely connected with refrigeration equipment air circulation capacity, so the rate may vary considerably depending on the type of equipment.

** L/s-tonne = Litres/second/tonne; cfm/ton = cubic feet/minute/ton. Conversion: L/s-tonne x 1.92 = cfm/ton.

For bulk storage, air is circulated through the pile by a fan and duct system. Temperature control is usually accomplished by a system of thermostatically controlled dampers that blend cold outside air with recirculated air. This system is linked to temperature monitors within the crop. This system requires the following:

- a proportioning thermostat to control the damper motors that set the ventilation temperature
- a low limit safety thermostat to turn the heat on if the temperature drops too low
- a differential temperature sensor to prevent ventilation with outside air that is too warm
- a timer
- damper control motors

Design of the air handling and distribution system should adhere to sound engineering principles. Ducts should be free of obstruction and adequately sized. Under-pile ducts should be spaced 2.4 to 3.6 m (8 to 12 ft.) apart. Storages built for crops requiring high humidity should have a high-capacity humidifier as an integral part of the system.

Simpler, low-cost ventilation systems suitable for shorter term or smaller storages can be devised. There can be fans and ducts (non-automatic) to circulate air through the pile, and manually operated doors and vents to bring in outside air for cooling. These systems sacrifice both accuracy and product quality.

Refrigerated storage

Refrigeration capacity is required if the intended storage period extends beyond the winter months, for early fall storage and for most “cold crop” storages. The refrigeration system should be designed to remove field heat (significant cooling load) and the heat that comes from crop respiration.

Plastic storage crates allow air to circulate through stored crop
Photo: Robert Spencer

The system should also be able to handle other heat gains, such as the heat that infiltrates the structure's walls, floor or ceiling and heat from lights or mechanical devices. The system must operate effectively at high humidity and near-freezing conditions, while also minimizing moisture loss from the produce. These requirements can be met by ensuring the refrigeration system has a large coil area, adequate airflow, defrosting cycles and humidification. Consult a properly certified engineer for assistance with design.

Various types of refrigeration systems are available. Each has its advantages and shortcomings. Systems can also be designed that combine outdoor air cooling with mechanical refrigeration as a means of reducing refrigeration costs.

When planning refrigerated or air-cooled storage systems (bulk or pallet), it is important that the direction of flow of refrigerated or cooled air through the produce be from coldest to warmest produce (usually from back to front). That way, heat removed from warmer produce does not reheat vegetables that were previously cooled. Condensation caused by warmer air striking colder produce is also prevented. Loading of the storage, and design of the airflow system, should be done accordingly.

When these cooling loads are taken into account, typical refrigeration capacity for vegetable storages should be as follows:

- cold crops: 130 to 165 watts per tonne (W/t) (410 to 510 British thermal units per hour per ton (BTU/h-ton))
- potatoes: 40 to 45 W/t (120 to 140 BTU/h-ton)

Controlled atmosphere storage
Controlled atmosphere (CA) storage involves modification of the storage atmosphere to slow crop respiration, thereby substantially extending the storage lifespan. In a typical CA storage, carbon dioxide (CO_2) levels are raised to 5 per cent from the baseline 0.04 per cent, and oxygen levels are dropped from the normal 21 per cent down to as little as 5 per cent.

Establishing and maintaining a controlled atmosphere requires an air-tight storage and special environmental control equipment. Producers must also consider the health and safety precautions required with this type of storage.

The cost to build and maintain a CA storage and related controls is at least 25 to 30 per cent more than a standard refrigerated storage.

Storage design
Standard plans for commercial-sized bulk vegetable storages and storage components, such as walls, doors and ceiling systems, are available from Canada Plan Service (see the Resources section in the Appendix).

Storage maintenance
Storages should be cleaned and maintained before use to reduce the potential for the spread of disease and other contaminants between crops. Clean and maintain all exposed surfaces (e.g. walls, floors) as well as any equipment or machinery that operates within the storage.

Thoroughly wash storage surfaces and equipment before applying disinfectants to maximize disinfectant efficacy. Use only disinfectants that are approved for use in vegetable storages. After disinfection, rinse all surfaces thoroughly before use.

TRANSPLANT PRODUCTION

Transplant Production

Introduction

The use of transplants is now a common component of vegetable production, particularly with the increased use of plasticulture technology and precision planting. The popularity of plug tray production increased with the development of less expensive plastic trays and the introduction of mechanical transplanters. Plugs are easy and fast to transplant, allowing crews to work more quickly and efficiently.

Transplants were traditionally grown in the soil in specialized nursery areas. However, transplant production under greenhouse conditions in soil-less media in trays has become much more popular, likely due to the ability to control the growth and development of the transplants and to provide a more uniform, quality plant.

Producers can order transplants from a specialty transplant grower or grow the transplants themselves. Purchasing transplants is an additional cost, but transplant production is a specialized process that requires specialized facilities and knowledge.

This chapter provides a brief overview of the different aspects of growing quality transplants.

Containers and trays

Transplants may be grown in a wide range of trays or containers. A variety of plug sizes are available, with larger sizes better suited to the production of larger transplants or sprawling crops.

A higher plug number per tray corresponds to a smaller plug size. Individual plugs or container units may be used (e.g. peat pellets), or plugs may be grouped in trays or containers. Select a plug size that will work in your transplanting equipment, that is suited to the chosen transplant medium and that is compatible with the crop you are growing.

Most large-seeded crops can be seeded directly into their final plug tray, as they should have no trouble germinating and will not require moving. Smaller-seeded crops may need to be started in a finer media, either in bulk flats or in small germination plugs. After germination and a period of growth, the small seedlings are moved into their final plug tray. Transferring seedlings from a starter plug or flat requires additional labour.

Growing media

Many types of growing media are available for the production of vegetable transplants. The growing medium needs to provide support for the seedling while also providing or storing the water and mineral elements required by the developing plant. Important characteristics of the medium are its composition, weight, porosity, moisture- and nutrient-holding capacity as well as freedom from contaminants or pests.

Field soil is rarely used in transplant production because it is heavy, non-sterile and has limited porosity and water-holding capacity. Some sterilized soil may be included in a transplant mix, but should not form the base of the mix.

Soil-less media are most commonly used for transplant production as they are more easily managed and are typically free of many of the challenges associated with soil-based media. Soil-less mixes are usually composed of a combination of peat moss and vermiculite or perlite. Other ingredients, such as sand, limestone and fertilizer, may be included in pre-mixed media.

Growing media characteristics

A good growing medium should be firm, dense, consistent, stable, porous and free of diseases and insects. It should also have good chemical properties such as low electrical conductivity (EC; salinity) and high cation exchange capacity (CEC).

All growing media should drain well. It is critical that all media have a balance between water-filled and air-filled pore spaces, to allow for optimal healthy growth. The porosity of soil-less media is adjusted by adding components such as peat moss and perlite.

Bulk density relates to the ability of the mix to support the weight of a plant. Bulk density is inversely related to the porosity of the mix. High bulk density mixes are heavy and low in porosity, and should be adjusted.

Cation exchange capacity is important because it can determine the amount of nutrients available to the plant or how well a medium will hold nutrients. Some flexibility in CEC is possible if fertilizers are added.

Soil pH is a measure of the acidity/alkalinity of a medium and is critical in controlling nutrient availability. Soil pH can be adjusted by adding various components (such as peat moss or lime) or fertilizer.

A good soil-less growing medium for vegetable transplants should have the following:

- pH of 5.5 to 6.0
- EC of less than 1 mS/cm
- CEC of 25 to 100 milliequivalents (meq) per 100 g of soil
- bulk density of 0.3 to 0.8 g/cm^3
- minimum total porosity of 35 per cent

A number of recipes for soil-less growing media are available from various sources.

The physical and chemical characteristics of a growing medium can change over time as a function of watering, plant growth and the addition of fertilizers. Be sure to regularly monitor the pH and EC of the growing medium, which can be done using affordable meters. The pH and EC of the medium can be adjusted by flushing the medium with water, reducing applied fertilizer rates and adjusting the pH of the nutrient solution.

Sterilization

In the past, many growing media contained soil or compost, which can harbour a range of disease and insect pests. Most modern media are based on components like peat and perlite/vermiculite, which are much less likely to harbour diseases or pathogens. If you create your own mix and intend on including non-sterile material, some type of sterilization process must be followed.

Sterilization can be accomplished using heat, steam or some commercial chemical sterilant. Sterilization kills diseases, insects, nematodes and most weed seeds. Use extreme caution if you are using chemical sterilants. They are extremely toxic, and the treatments must be applied in such a way as to reduce the risk of injury, residual effect on plants, etc. Be sure to follow all covering, aeration and interval requirements for whichever method you choose.

To prevent the introduction and spread of pest organisms into sterile media, all pots, flats, bins, beds and tools should be disinfected before use and between crops, if possible.

Transplant production

Seeding

Seeds should be planted at an appropriate depth, which typically relates to the size of the seed. Very small-seeded crops are typically seeded on the surface and covered with a light covering of media. Most crops are seeded 6 to 13 mm (0.25 to 0.5 in.) deep. Larger-seeded crops (cucurbits, etc.) are seeded up to 25 mm (1 in.) deep. (See Table 25, Vegetable plug production requirements, for seeding depths by crop type.)

Increase seeding rates to compensate for a low germination percentage or adverse production conditions.

Fertilizer

Most growing media already contain a small amount of available nutrients, but supplemental fertilizer will be needed to produce healthy transplants.

Dry fertilizers can be added to growing media. However, it is difficult to apply enough fertilizer to meet the requirements of the transplants without causing some salt burn. It is also difficult to get uniform distribution of dry fertilizer granules within the limited volumes of media contained in a typical transplant cell.

Additional fertilizers in the form of slow-release granules or as a liquid can be used to supplement any dry fertilizers applied before planting. The majority of all applied fertilizers should be in a readily available form, as there will be little time for breakdown and release to the plants.

Applying fertilizers dissolved in water (fertigation) is the most accurate and efficient means of fertilizing vegetable transplants. For most vegetable transplants growing in a soil-less medium, 250 ppm of nitrogen and potassium should be applied in the irrigation water on a weekly basis, or smaller amounts can be applied in every watering.

When soluble fertilizers are applied, enough irrigation water should be used to moisten all the growing medium in the tray. There is a danger of soluble salt accumulation if the medium is not watered thoroughly. Water with fresh water or apply an excess amount of water periodically to flush out any residual salts. Also, wash off liquid fertilizers to prevent burning the leaves.

Minor adjustments in the concentration of the fertigation solution may be made according to growth stage and crop growth. For example, fertilizer rates may be reduced as plants are hardened off before placement in the field.

Moisture

Water quality

The mineral content of your water can significantly affect the health of the transplants. Certain elements can negatively affect growth or alter the growing medium characteristics. Test water periodically, before and during the production cycle.

Closely monitor the boron, chloride, sodium and bicarbonate content of the water. The boron concentration should be less than 1 ppm, and the chloride concentration should be less than 10 ppm.

The sodium adsorption ratio (SAR) should be calculated to determine the effect of sodium on the growth of plug seedlings. This ratio represents the amount of the detrimental element sodium in the water relative to the amounts of the beneficial elements calcium and magnesium. Water with an SAR value greater than 2 may be harmful to plants.

Bicarbonate in the water causes the pH of the medium to increase over time. The total amount of bicarbonate should be less than 4 milligrams (mg) per litre. Changes in the pH of the growing medium can be countered through acidification of the water using phosphoric or nitric acids.

Watering

Proper water application is important for germination and continued healthy plant growth and root development.

During the germination stage, apply water as a fog or fine mist to avoid washing out shallow-planted seeds. Water may be applied with a boom irrigation system, but careful attention is required to avoid overwatering.

Once seedlings have begun to emerge, apply less water so that the medium will not be saturated; this approach will allow more aeration. As the plants grow, they should be watered thoroughly but less frequently.

Temperature

Temperature is critical to germination and seedling growth. Cold temperatures will slow growth and encourage disease, whereas temperatures that are too warm may cause spindly or weak growth.

Depending on the crop, temperatures ranging from 24 to 30°C (75 to 86°F) are recommended during the germination stage (Table 25). After

Table 25. Vegetable plug production requirements									
Crop	Number of weeks required	Seeding depth		Temperature required					
		(mm)	(in.)	Germination		After emergence		Growing-on	
				(°C)	(°F)	(°C)	(°F)	(°C)	(°F)
Broccoli	5 - 7	6	0.25	24	75	15	60	10	50
Brussels sprouts	5 - 7	6	0.25	24	75	15	60	10	50
Cabbages	5 - 7	6	0.25	24	75	15	60	10	50
Cauliflower	5 - 7	6	0.25	24	75	15	60	10	50
Celery	9 - 10	3 - 6	0.125 - 0.25	24	75	15	60	10	50
Cucumbers	2 - 3	13	0.5	32	90	18 - 24	65 - 75	18 - 24	65 - 75
Eggplants	7 - 8	6	0.25	27 - 29	80 - 85	21	70	15	60
Lettuce	4	3	0.125	24	75	15 - 18	60 - 65	15 - 18	60 - 65
Melons	4 - 5	13	0.5	32	90	18 - 24	65 - 75	18 - 24	65 - 75
Onions	10 - 12	6	0.25	29	85	13 - 24	55 - 75	13 - 24	55 - 75
Peppers	7 - 8	6	0.25	27	80	21	70	15	60
Tomatoes	5 - 6	6	0.25	27	80	18	65	15	60

germination, temperatures are typically reduced to about 18 to 22°C (64 to 72°F) to allow optimum photosynthesis. To harden off plants, the temperature should be decreased to about 15 to 18°C (60 to 65°F).

Light

Maximum light is always recommended and should approach at least 48,500 lux (4,500 foot candles) even on a cloudy day.

Disease management

Damping-off, seed rots

Germinating vegetable seeds and seedlings are susceptible to disease infection, and problems are common if proper management practices are not in place. Seed can rot in the soil, or seedlings can die before they come up or topple over soon after emergence.

In damping-off, the stem tissues at the soil line are attacked by fungi. The infected tissues become water-soaked and turn brown or black. Damage to the vascular system disrupts the flow of water from the roots to the top of the plant, leading to slow growth and wilting.

To prevent damping-off and other seed/seedling issues, follow these recommendations:

- Disinfect soil.
- Treat seed with fungicides.
- Drench the media with fungicides.
- Provide good ventilation.
- Water in the morning; do not overwater.
- Do not sow seeds too thickly.
- Keep humidity low.
- Ensure plants are held at proper temperatures.

If damping-off appears, seedbeds may be drenched with a registered fungicide. However, prevention is preferred over trying to fix a problem.

Insect pest management

A number of greenhouse insect pests may cause problems in transplant production. Management of these pests may be required, either in the greenhouse or shortly after plants are set in the field.

In general, insect pests may be dealt with during transplant production by several methods:

- Control weeds inside and around the greenhouse (use care; chemical drift or volatiles can move in through ventilation systems).
- Avoid bringing infested plant material into the greenhouse.
- Screen the vents and other openings to prevent insect entry from outside.
- Apply registered control products. Note that some products are not registered for use in greenhouses on some crops, but are registered for application once transplants are set in the field.

Among the insect pests found in Prairie greenhouses, the most common are fungus gnats, aphids, thrips and mites.

Fungus gnats are small, delicate, dark grey or black flies about 3 mm (0.10 in.) long. They are often seen running on the soil surface or flying around potted plants, especially in wet areas. The slender white larval stage of this insect pest has a shiny black head and lives in the soil. Fungus gnats feed on decaying organic matter plus algae and are common in manure and compost. The larvae may damage roots of seedlings, rooted cuttings and young plants.

To manage fungus gnats, avoid overwatering and ensure good drainage under the greenhouse floor and benches. Strict sanitation is also important, removing debris and plant material from the greenhouse and controlling algae. Yellow sticky traps hung near the soil surface can catch flying adult fungus gnats. Registered chemical controls may be used to reduce populations of fungus gnats, but cultural controls can help keep populations to a manageable level.

Aphids and thrips may cause more damage than fungus gnats. Thrips can significantly alter the growth of the plant as they feed on growing points. Aphids carried from the greenhouse can cause an aphid problem in the field.

For general information about mites, refer to the text about Mites in Common Insect Pests of Vegetable Crops (Insect Pest Management section in the Pest Management chapter).

Field transplanting

Ideally, mature transplants are transplanted immediately upon removal from the greenhouse. Sometimes, the weather does not co-operate, and the transplants have to be held over.

Holding over actively growing plants slows their growth process and adds to the time of production. When mature transplants are held over for longer than a week, a loss of actively growing root hairs occurs. Plants may also become root bound, which slows establishment in the field and increases total crop development time.

If transplants cannot be set out as scheduled, ensure that the roots do not dry out. Temperatures favourable for growth (20 to 25°C; 68 to 77°F) are optimum for holding these plants for short periods. Soil temperature should not drop below 16 to 18°C (61 to 64°F).

When transplanting, water the plugs a couple of hours beforehand to make them easier to dislodge. After transplanting, apply a starter solution of 10-52-10 (1.5 to 1.8 kg in 189 L of water; 3 to 4 lb. in 50 gallons) or similar starter fertilizer to the transplants to provide the early boost they need to set new roots in the field.

For more detailed information on the placement and use of transplants in the field, see the section on Transplanting in the Field Production Chapter.

PEST MANAGEMENT

Pest Management

Managing pests in vegetables

One of the major challenges in vegetable crop production is protection of the crop against pests such as pathogens (diseases), insect pests and weeds. Pest management consists of the tools and techniques for identifying and minimizing the effects of pests on the crop.

Integrated pest management

Historically, pest management focused on the control of pests through repeated use of a limited number of pesticides. This practice resulted in a gradual deterioration of the efficacy of control measures as it selected for pests that were resistant to the commonly applied pesticides.

In recent years, greater emphasis has been placed on an integrated approach to pest management. Integrated pest management (IPM) is defined as a "broad interdisciplinary approach using scientific principles of crop protection fused into a single system using a variety of methods and tactics."

In layman's terms, IPM involves the use of many different tools and techniques to manage pests, with careful consideration of all factors that influence pest populations and the potential for the pests to cause damage to the crop.

Integrated pest management includes the following strategies:

- breeding crop varieties for pest resistance
- regular scouting and monitoring of targeted pest species, including identifying pests and tracking changes in pest populations (incidence and severity)
- using economic thresholds to determine when control practices should be implemented, allowing some degree of crop damage to occur
- using a diverse set of management tools, including chemical, cultural and/or biological options, without relying solely on one tool
- focusing on suppression of pest species to below economic threshold levels, rather than on eradication
- considering the effect of management options on both the pest and non-target species (e.g. beneficial predators)

Pest management planning

It is important to prepare in advance for pests, whether they show up or not. It is easier to protect a crop or reduce the potential for pest development than to try to control an established problem.

Pest management must start before the crop has even been planted. Consider crop selection, crop rotation, field layout and orientation, plant spacing, the different pests that might be expected and the pest management options.

What pests were present in the field in the past or might be present in the adjacent fields? What techniques help control them and how well do they work? How are rows oriented and spaced? Can tillage or spray equipment pass safely between rows? Can plants be spaced further apart to improve airflow and reduce humidity and, thereby, reduce potential disease levels in the crop? These and other questions must be answered when preparing field and cropping plans.

Scouting and monitoring

Scouting is the process of regularly moving through the field looking for evidence of disease, weed and insect problems. This is an active process, with scouts taking samples, examining plants, attempting to capture and count pests, and generally creating a map of each field and the pest populations in it.

Scouting needs to be a regular process to watch for the presence of pests, monitor changes in pest distribution, severity and numbers, and assess the effectiveness of any control practices employed. The more information you can gather, the better informed your pest management decisions can be.

Scouting and monitoring can have the following benefits:

- correct pest identification
- early detection of problems
- better understanding of pest populations, including numbers and distribution
- better understanding of when pests are at susceptible life stages
- better understanding of impact on crop by pests
- information for better management decisions
- potential to reduce the number of pesticide applications and so reduce pesticide costs
- potential to apply management practices to targeted areas as opposed to the entire field

Scouts need to be properly trained and attentive. Regular scouting should be done by the same person, if possible, so changes can be recognized and acted on. Scouts should keep careful records and identify any problem areas.

For effective scouting, conduct a thorough survey once or twice per week. This activity is more than just a drive-by survey. It requires walking through the field in a zigzag pattern and stopping for close examination of individual crop plants at 10 to 12 sites per field. The number of sites may be increased for larger fields.

At each site within the field, inspect plants with the light behind you. Look closely at the plants, including inside the canopy, under the leaves and within the nooks and crannies of the plants. Dig up plants to examine the roots if symptoms indicate some sort of issue that may be linked to the roots. Be prepared to sacrifice a plant if it will provide information that will help prevent a bigger problem.

Take good quality digital pictures, starting from an outside perspective and moving the focus into the individual symptomatic plant parts. If necessary, collect samples and have the insect/disease/weed properly identified. Take notes and keep records of all scouting activities. These notes can be useful in future pest management planning and in monitoring ongoing issues from year to year.

Scouting tools

When you go scouting, bring along the tools needed to most efficiently collect information. Here are possible tools for a "scouting toolbox":

- sweep net – for capturing and quantifying various insect pest populations
- hand lens – for examining symptoms and insects
- small knife – for taking samples, etc.
- non-metallic pie plate – for catching and counting certain types of insects (e.g. tarnished plant bug)
- metre stick – for measuring rows because some economic thresholds are per unit length of row
- trowel or spade – for digging root, crown or soil samples
- pencil or pen and paper (including labels for samples, a notebook, etc.)
- digital camera or a decent quality camera phone – for use in pest identification and for tracking problems. Be sure you know how to use the camera. A camera phone allows you to transmit pictures from the field. Pictures should be in focus and should include some sort of object for scale and perspective.
- paper bags – for fresh plant tissue samples because samples are less prone to rotting in paper bags than in plastic bags
- plastic bags – for soil samples or other samples
- small vials or jars – for collecting insect samples; may contain ethyl alcohol (ETOH) to kill and preserve the samples
- cooler – for keeping fresh samples from overheating and rotting
- flagging tape or marker flags or GPS marking equipment – for flagging problem areas for spot spraying or continued monitoring

- insect, weed and disease identification books – for quick and easy identification of problem symptoms
- basic biology dissecting kit (contains scalpels, tweezers, probes, etc.) optional – for use in more complex identification or collecting smaller samples

Diagnostics

Along with identifying specific problems, the scout needs to gather information to help determine the cause and scope of the problem and assist in pest management decision-making.

Diagnosing a problem is somewhat like unwrapping a present or peeling an onion. You have to slowly and carefully collect information by gradually moving your focus in from a field scale to the individual plant part that is affected. The more information you collect, the more information you will have to help rule out certain issues or identify causes and assist in decision-making.

Start by determining what crop or crops are affected. Is the problem restricted to a single crop or is it in a number of different crops? How widespread is the problem within each field or in the production region? Does the field or crop have a history of problems (recent or further back)? Are only individual plants affected, or are there patches in the field? Is there a pattern to the problem? Does the problem appear to be spreading, and if so, how is it spreading? What stage is the crop at?

Also, collect information on the overall field conditions and both current and past production practices. What has the weather been like? What is the current moisture situation in the field or in specific locations, if relevant? Is it an irrigated field? What is the fertility situation? What is the weed situation? What sprays have been applied to the field this year and in previous years?

After gathering this more general information, then move into a more specific examination. What are the general plant symptoms? What part or parts of the plant appear to be affected? Is there evidence of insect pests or insect activity (past and present), such as chewing, boring, debris or frass (waste matter) from the insects? Is there evidence of fungal or bacterial pathogens, such as lesions, decay, bacterial ooze, fungal sporulation or fruiting bodies? Is the plant distorted or displaying abnormal growth in any way?

Take specific note of the appearance of damage, including the shape and colour of lesions, type of feeding damage or the way an insect looks and moves.

Identification

Samples collected during scouting will need to be examined to identify the specific pest or problem and determine its significance and potential effects.

Sometimes it is easy to figure out the cause of a specific issue. At other times, you may need to use resource materials (such as books, websites, etc.) or diagnostic services in your province.

Submitting a sample to a diagnostic lab will allow experts to do further and more precise testing. In some cases, this analysis may involve allowing an insect to develop to a further life stage for easier and more accurate identification. In other instances, examination under a microscope will reveal features not visible to the naked eye. Culturing or growing a pathogen in specialized conditions can also allow identification.

Economic damage thresholds

The presence of a pest in a field does not mean it must be eradicated. Healthy, actively growing plants can tolerate some damage or competition without significant yield loss, although "significant" is a fairly subjective term. Economic thresholds can be used to determine when or if you need to spray.

Economic thresholds are calculated by determining the losses that may come from a particular pest compared to the cost of the treatment(s) that will be required to control the pest. By watching the changes in a pest population, you can determine how quickly the population is growing and estimate when it will reach economic levels.

When determining economic damage thresholds, it is important to understand how the rate of pathogen or pest development and growth are influenced by environmental conditions, such as temperature, moisture and other factors.

For a disease or pest to occur, grow and develop, three conditions must be met. First, there must be a susceptible host. Second, the pathogen or insect pest must be present in the field. Third, there must be suitable environmental conditions for the pest to develop. Having each condition present, and in different degrees, determines the amount of pest activity.

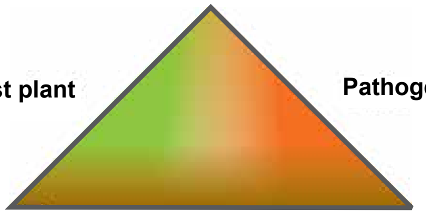


Figure 5. Disease triangle depicting relationship between host plant, pathogen and environment

For example, for a specific disease to occur on the leaves of a crop, the crop must be a host for the particular pathogen and susceptible to it. Some pathogens, such as powdery mildew, are very host-specific and will only harm certain host species. The level of susceptibility of a particular crop can be affected by the cultivar grown, the crop stage, stress, damage, etc. At the same time, the pathogen must be present.

And environmental conditions favourable to the pathogen must be present. If a pathogen requires cool and moist conditions to thrive, then hot, dry, windy conditions will result in little disease development, even if the pathogen and the host are present.

By considering each of the three factors, you can determine the likelihood of a pest developing quickly and whether it will cause an economic effect.

Other factors may also weigh into the calculation of economic thresholds. Examples include the ability of a pest to develop after harvest, the crop stage at which the infection or infestation takes place (how much time is left for it to develop before harvest) or what part of the plant is being affected, relative to the part that will be harvested (e.g. fruit versus leaves).

Basically, economic thresholds are affected by criteria unique to each situation. Two key criteria are the value of the product and the potential economic effect from either decreased yield and/or reduced quality. These criteria are determined by the market and the tolerance of the buyer/customer.

If your customer's tolerance of pest damage is low, then your economic threshold will be low, meaning you will implement control strategies earlier. Another important criterion is the cost of the pest management program. Cost can be in purely economic terms, but may also include cost to health, the environment, etc.

Risk management

Pest management involves the assessment of risk. There is the immediate risk of crop loss (failure) or economic loss due to lost yield or reduced quality. There is a risk to your reputation and the potential long-term loss of markets if you deliver a poor quality crop or fail to deliver because you could not control the pests. These risks need to be balanced against the risk of minimal returns and wasted resources from an unnecessary or unsuccessful control treatment.

Two other risks that must be considered are the potential for the pest population to build up to uncontrollable levels and the risk of the development of a resistant pest population. Relying on a single pest management tool is a risk.

There may also be a risk of injuring or reducing beneficial insect populations (e.g. pollinators, etc.) or a risk of damaging the environment, yourself and/or workers or the crop itself.

Minimize these risks as much as possible. This approach should involve regular rotations of crops, fields and control options to spread out your risk. Also, you need to have a thorough understanding of potential pests, pest population dynamics and damage thresholds as well as the market requirements for quality and any pest damage that might affect that quality.

Control options

In the spirit of integrated pest management, the term "pest control" is really a misnomer because control implies a 100 per cent removal of a problem. "Management" is a better term, as there is allowance and flexibility for the continuing presence of the pest and some associated loss or damage.

Various tools are available for managing vegetable crop pests. To choose the best options from the range of tools available, producers need to balance the benefits from a particular option against its costs. For example, a specific chemical treatment may be very effective but very expensive, whereas a cultural treatment may be cheaper, but not as effective. If complete control is more important, then the higher cost may be justified.

Remember that there are both direct economic costs, such as the application costs, and hidden costs (environment, health, loss of efficacy from repeated use, etc.) when using any treatment.

As much as possible, rotate among control options. If one control method is used repeatedly, it will eventually become less effective or may create other problems. For example, continued reliance on cultivation for weed control can lead to the development of a compacted layer or a weed population that is not controlled by cultivation. Similarly, the repeated use of a single insecticide will eventually result in the selection of a population of insects resistant to that product.

Chemical groups or families of herbicides, insecticides and fungicides have different modes of action. Rotating among products from different chemical groups reduces the risk of the development of pesticide resistance.

Cultural controls

Cultural control or management practices involve activities or practices that either enhance crop growth or alter conditions in a manner unfavourable to crop pests.

Cultural options include mechanical practices like tillage and mowing, which provide some degree of control of various weed, insect and disease problems. For example, tillage buries crop residue, which hastens its breakdown and thereby reduces the potential for a residue-borne disease to carry over into the next crop. Tillage may also bury some insect pests while exposing others to desiccation or bird predation. Mowing field margins can disrupt overwintering areas for pests like the Colorado potato beetle (CPB) but may also displace predators of some of the common insects pests.

Other cultural practices aim to enhance crop growth, either to encourage the crop to grow past a particular problem (e.g. out-compete a weed) or to stave off infection by being less susceptible to attack. Standard crop management practices such as fertilization or irrigation help promote rapid, healthy growth. Over-fertilization or overwatering can have the opposite effect, increasing crop susceptibility to disease and improving conditions for pest development.

Cultural practices may also involve creating conditions unfavourable for the growth of pest species. The risk of many diseases can be reduced by employing practices that ensure good airflow through the crop canopy, such as proper spacing of plants and careful orientation of rows and fields. Selection of land with good drainage (air and water) is also important. Timing irrigation so that the leaves dry off quickly can also reduce disease. Maintaining a rotation between different crops can break disease and insect pest cycles. Staggering or altering planting dates can help avoid having susceptible crop stages coinciding with times when pests are particularly problematic. Using resistant varieties, if available, can also be a successful practice.

Biological controls

Biological controls consist of natural organisms that compete with, antagonize or prey on specific pest species. Bio-control agents can include bacteria, fungi, parasitic insects or some other type of non-pest species. Producers may encourage and rely on native populations or may introduce the bio-control agents.

Bio-control agents do not eradicate the pest, but they can be used to maintain pest populations below the economic damage threshold. Biological controls are typically very pest-specific, which means they have relatively limited potential to damage non-target or beneficial populations.

Biological controls are used in different ways. For instance, when bacteria or fungi are used to suppress root rot pathogens, the bio-control agent is applied to the seed or placed in the seed row (pre- or post-planting) so that it is in the root system before the pathogen attacks the plant. The bio-control agent(s) may colonize the same area on the roots that the pathogen would normally inhabit, thereby denying the pathogen access to the root. Alternatively, the bio-control agent may attack pathogens in the soil or growing medium before the pathogens are able to infect the plant.

Where a bacterial or fungal agent is used to control insect pests or weeds, the biological agent is sprayed on the plants so that it comes in contact with and attacks the target pest.

Many insect species can be used as bio-control agents (predators, parasites and parasitoids) for other insect pest species. Predators are species that prey on other species, killing them and feeding on them, similar to a carnivorous animal like a lion preying on a gazelle. Parasites and parasitoids attack pests by laying their eggs in or on the target pest. The larvae then develop and feed within and/or on the pest, usually resulting in its death.

Some insect bio-control agents can rapidly consume large numbers of pests. Insect bio-control agents usually require the presence of the pest to maintain a population of the agent.

Following the introduction of the bio-control agent, its population spreads out into the crop to find and attack the target pest. If conditions are suitable, the population may thrive and grow, resulting in highly effective long-term pest control. However, this process is not certain and takes time.

If more rapid control of a large pest population is required, the bio-control agent can be introduced in very large numbers (a.k.a. inundation), but costs will be higher. In most cases, it is wise to try to maintain a stable population of bio-control agents and re-introduce them, if required.

Bio-controls are often used in greenhouses where conditions are stable, crops are maintained for long periods, and populations of biological agents can be contained and easily monitored. In a field situation, it is difficult to maintain an introduced population; however, there can be some success with using inundations of bio-controls for some pests.

When using bio-controls, be aware of the effect of chemical pesticides or other treatments on those biological species, as these agents may be more susceptible to the treatments than the target pest.

You can encourage native predators, parasites and parasitoids to become established in your fields through careful and minimal pesticide use or by establishing natural habitats, such as by leaving field margins untilled. Encouraging a healthy microbiological balance in the soil and around the crop area can be another way to help keep pest populations at manageable levels.

It is important to accurately identify beneficial species, rather than assuming that all insects or fungi are pests. Consider the effect of pest control treatments on beneficial species.

Chemical controls

Chemical controls are commonly employed for pest management in vegetable crop production. Chemical control products fall into a range of types or classes, depending on their chemical composition, mode of action, target pest(s), registration type, application method, etc. It is important to fully understand how each product works, so you can use the products to greatest effect with the least amount of risk.

Types

Chemical control agents are commonly grouped based on the target pest. Herbicides are used for the control or suppression of weed species, but they may also kill or injure crop species. Fungicides are used to manage fungal pathogens. Bactericides or antibiotics are for control of bacterial pathogens. Insecticides are used to control insect pests, although some products also control pests that are not true insects. Miticides are used to control mites (which are not true insects). Soil sterilants kill a broad spectrum of organisms (insects, weeds, nematodes, fungi, bacteria) in the soil.

Classes
Pesticides are placed into different classes (numbered and lettered groups) based on the way the active ingredients act on the target pests, whether it is through disruption of function, toxicity, etc. Pesticides of the same type (e.g. fungicides) that have the same number or letter designation have similar modes of action and should act on pests in a similar manner.

Pesticides are placed into numbered groups by several crop protection industry committees:

- Fungicide Resistance Action Committee (FRAC)
- Insecticide Resistance Action Committee (IRAC)
- Herbicide Resistance Action Committee (HRAC)

Mode of action
The mode of action depends on the pesticide's spectrum of activity and its mechanism of affecting the target species. In the past, pest control products tended to be fairly broad spectrum in activity. Broad-spectrum activity allowed the use of a single product to control a number of pest problems. However, these products were often toxic to non-target species. In recent years, there has been a switch to products that are much more species-specific.

Many products target a specific metabolic, physiological or developmental processes of a pathogen, weed or insect pest species. Some products do not result in the immediate death of the pest, but instead, they impair the pest's ability to damage the crop. For example, some chemicals cause the target insect pest to stop feeding, which immediately stops crop damage but only eventually results in the death of the pest by starvation.

Growers need to be aware that, after application of such a product, the pests may take some time to die. Otherwise, growers might incorrectly assume that the product was ineffective and re-apply it or apply other products, at a greater cost. Be sure to understand how a product works so as to use it most effectively.

A chemical's group designation can be found on the pesticide label. By rotating among products with different modes of action, you can avoid or slow the buildup of pesticide resistance in a pest population.

Application methods
Pesticides are applied in different ways. The main goal of any product application is to deliver the correct amount of product to the area where the pest species is or to the area susceptible to damage by the pest. In some instances, the goal is not to bring the product in direct contact with the pest, but rather to form a toxic barrier the pest will have to come in contact with to reach a plant.

Herbicides are classified two ways: pre-emergent, applied to the soil before weed germination and growth or post-emergent, applied to actively growing weeds. It is important to recognize how the application of these products interacts with or affects the activities associated with crop production. Products may affect crop growth if they are misapplied.

Non-selective herbicides are applied to growing vegetation and will either kill any growing tissues or will be translocated back into the plant to kill the entire plant. These products will kill crops just as effectively as they kill weeds.

Take care when applying any type of herbicide as they have a significant potential for killing the crop or crops in adjacent fields if misapplied. Herbicide residues can injure crops in the years following application, depending on product type, soil conditions, weather, rate of herbicide breakdown and sensitivity of the subsequent crops.

A fungicide or insecticide may be applied as a foliar spray, a soil drench or a seed treatment. Both fungicides and insecticides include products that provide direct, contact control of pests as well as products that can be taken up by the plant to provide systemic protection (i.e. products moved from the site of application to other locations in the plant).

Pre-harvest interval and re-entry interval
Because pesticides are applied on or near the crop, some amount of the pesticides will be present on the crop for a time after application. Every pesticide has a minimum interval between the last application and when the crop may be harvested.

This pre-harvest interval (PHI), or days-to-harvest interval (DHI), must be adhered to when applying any pesticides to be compliant with pesticide application and on-farm food safety (OFFS) systems regulations and to minimize residues that may potentially harm consumers.

In addition to a PHI, most products have a minimum interval between chemical application and when the field can be re-entered safely. This re-entry interval (REI) is meant to protect applicators, field workers and other people who might enter the field.

Whatever a product's mode of action or method of application, use care and caution when applying it to prevent injury to non-target organisms, including the applicator. All producers must follow all label directions.

Chemical rotation
As has been mentioned, rotating among a range of products with different modes of action helps prevent the buildup of resistance in a specific pest population. Chemical rotation can also prevent excessive buildup in the field of a product (e.g. herbicide) that might injure subsequent crops.

Weed management

Weeds compete directly with crops for light, space, water and nutrients. Weeds can also provide an environment favourable for the growth and development of diseases and insect pests. As well, weeds may serve as alternate hosts for many insects and diseases.

The cost and effort required for weed control can be reduced through good land management. Generally, weeds are best controlled by a combination of cultural and chemical methods.

Take time before planting your crops to control existing weeds. The control of perennial weeds like quackgrass and Canada thistle is really only possible outside the cropping period. By spending time on general weed management before planting, you can reduce in-crop weed control requirements.

Depending on the crop, various weed management options are available. As with all pest management tools, you need to be sure to vary your weed control methods to prevent the buildup of a resistant pest population.

Cultural weed control

Cultural weed control options in vegetable crops include crop rotation, tillage, hoeing and mulching. General options include the following:

- **Fallow**: Leaving the field fallow may be done either as a part of the entire crop rotation or before planting the crop. This tool is particularly valuable in controlling perennial weeds. Fallowing can be done mechanically or using non-selective herbicides.
- **Crop rotation**: Switching between different types of crops may permit the use of alternate herbicide chemistries or other strategies to control problem weed species. For example, most vegetable crops are broadleaf species, which results in limited options for the control of broadleaf weeds in these crops. Therefore, rotation with cereal crops provides many more options to control broadleaf weeds. Be sure to take into account the duration of residual activity of any pesticides used in the rotation and how that activity will affect subsequent crops in the rotation.
- **Plastic mulch (black or wavelength-selective)**: The use of plastic mulch can add significant expenses to an operation (in terms of equipment, labour and material), but the mulch is very effective at suppressing weed growth within rows. Using plastic mulches is most compatible with transplanted crops. Weeds will need to be controlled between the rows of plastic mulch.
- **Green manure**: In green manuring, a highly competitive legume crop – like alfalfa, clover or peas, or a winter cereal, such as fall rye or winter wheat – is planted at the end of the crop season (in the fall), in fallow years or

perhaps between the rows. The green manure crop serves two main functions: it produces an aggressive, fast-growing canopy that outgrows weed competitors, and it produces a large amount of organic matter, which can be ploughed back into the field. A legume green manure will provide the additional benefit of fixing nitrogen.

The green manure crop is mowed, chemically killed or ploughed down before planting the next crop. An annual green manure should be ploughed down or killed before seed set. If mowed down, green manure crops produce a thick mulch of vegetation, which may stop weeds germinating but may also stop the crop from germinating.

When choosing green manure crops, consider allelopathic effects (reduction in plant growth due to exposure to chemicals produced by other plants) of decaying organic matter from the green manure crop.

Weed seeds are spread by wind, water, animals (on the animals or in their manure) and human activity. However, the main sources of re-infestation and increases in weed populations are from seeds produced by existing weeds in a field.

One of the main goals of cultural weed control is to gradually deplete the reservoir of weed seeds in the soil. This process is definitely long term. Weeds are prolific seed producers, and the seeds of many weed species can remain dormant and viable in the soil for years.

Even after maintaining perfect weed control in an area for a number of years, growers may still experience weed problems. Weeds have the potential to increase rapidly and re-infest a field if vigilance is relaxed.

A long-term weed prevention program should include the following strategies:

- Stop existing weeds from producing seed. This process involves removing seed heads or killing weeds well before they set seed. Remember that some weed seeds are viable (or may become viable) even if the weed does not appear fully mature.
- Avoid introducing weeds during planting. Check crop seeds for the presence of weed seeds. Inspect transplants and tubers for weed seeds or rhizomes of perennial weeds. Purchase seed, transplants and tubers from reputable suppliers.
- Avoid spreading weeds with equipment. Thoroughly clean tools, tractors and other implements before moving them from one area (especially if weed-infested) to another.
- Manage weeds in non-crop areas. Prevent weeds from setting seed in rough areas adjacent to cropped areas, such as fence lines, roadsides and farm yards. Keep irrigation ditch or dugout banks and structures weed-free to avoid the spread of weed seeds by water flow.
- Compost manure. Thoroughly compost manure from livestock that have been fed weeds, screenings, or grain or hay containing weed seeds until most weed seeds have been killed.

Chemical weed control

No single herbicide will control all weed species in all crops (without also killing the crop). Herbicide choices are based on which weed species need to be controlled and which crop they are in.

Weed identification is critically important for making the proper herbicide selection. Various publications are available to assist in weed identification (see the Resources section in the Appendix). Proper timing and application of herbicides are also important to ensure success. Weeds are generally most susceptible to herbicides at the seedling stage. Optimum weather conditions enhance herbicidal activity.

Specific recommendations for registered weed control products in vegetable crops are not presented in this manual due to regular changes in registration and the availability of product. Consult herbicide labels for specific rate and application details. Consult provincial government or chemical company resources for assistance with product selection.

Perennial weed control
The vegetable production site should be free of perennial weeds before planting the crop. Perennials are virtually impossible to control within an established vegetable crop.

Perennial weeds may be controlled with the application of non-selective herbicides, with this process starting 1 to 2 years prior to vegetable planting. The product should be systemic, with the ability to be translocated throughout the plant to kill non-exposed portions.

Generally, ensure that weeds are actively growing before the application of systemic products. Then, delay cultivation for 5 to 10 days after application to allow the product to fully move within the plant.

Stale seedbed technique
The objective of the stale seedbed technique is to produce a weed-free environment for germination and emergence of the vegetable crop. The technique involves the following steps:

1) Till the seedbed 2 to 4 weeks in advance of seeding to stimulate weed germination and emergence.
2) Seed the vegetable crop without re-working the seedbed.
3) Apply a non-selective contact herbicide or other non-residual weed control method (e.g. heat) to "burn off" emerged weeds before the crop has emerged. If the treatment contacts the emerging crop, damage or crop failure will result.
4) Once the crop has emerged, avoid any subsequent tillage to prevent stimulating germination of any further flushes of weeds.

Ensure that there is sufficient time between the treatment and crop emergence to prevent crop injury. Remember that the stale seedbed technique will not provide any residual weed control.

Pre-plant incorporation
Pre-plant incorporated (PPI) treatments are applied before the crop is planted. These herbicides generally kill weed seedlings as they germinate. Most PPI herbicides must be thoroughly incorporated into the soil by tillage or cultivation soon after application; otherwise, there will be a loss of product efficacy. Soils should be free of large clods and crop residue to permit uniform incorporation of the PPI herbicides.

Pre-emergent application
Pre-emergent products prevent weed emergence. Apply the product immediately after seeding or at least before emergence of the target weeds to provide adequate control. If these herbicides are applied after weeds have emerged, the kill is usually poor. Best results with pre-emergent herbicides are obtained when conditions are favourable for weed seed germination. Rainfall or irrigation water applied after application of the herbicide is generally required to activate these herbicides.

Post-emergent application
Post-emergent herbicides are designed to control emerged weeds and are applied after the crop plants are up. If these products are applied as directed, susceptible weeds will be killed without injury to the crop. The weeds should be small for best results. Good growing conditions usually enhance the level of weed control achieved with post-emergent products.

Crop injury from herbicides
Herbicides have the potential to cause significant crop injury and loss. Many weeds are closely related to crop species, which makes it difficult to find herbicides that will control the weeds without harming the crop. In most cases, crops are merely tolerant of the rates of the specific herbicides applied. Over-application of a product or exposure of the crop to other products will result in damage.

Drift and residues
Spray drift occurs when some form of pesticide drifts or floats onto a non-target species or area. Drift can damage or destroy susceptible vegetable crops for a great distance from the target treatment area. Even if the crop appears undamaged, there is the potential for residues to be in and/or on the marketable portion of the crop. These residues can render that crop unmarketable.

Many vegetable crops are extremely sensitive to chemical injury, with herbicide drift posing the greatest risk. Pay careful attention to the type of product, the sensitivity of adjacent crops and the direction and speed of the wind when applying a herbicide. Select appropriate nozzle types, application pressures, etc. to minimize drift. Use low pressures whenever possible (205 to 240 kPa; 30 to 35 psi) to increase droplet size.

In some provinces (e.g. Manitoba), online resources are available to assist producers with determining if conditions are suitable for spraying in their area.

All spraying equipment must be washed and rinsed thoroughly between applications. Do not use the same sprayer to apply herbicides as those used for applying fungicides and insecticides, unless the correct detergent or cleaning agent is used. There is a significant risk of carry-over residues, even if good washing practices are used. Drain tanks and equipment thoroughly, and wash out all sprayer equipment immediately after use.

Do not mix a herbicide with other herbicides or other chemical products (e.g. insecticides, fungicides, foliar fertilizers, surfactants or detergents) unless the mixture is specifically recommended by chemical company representatives or competent authorities. Improper tank mixing can result in changes in physical and/or chemical properties that can affect the way products work.

Herbicide residues are a major concern when planning your crop rotation or when purchasing or renting new land. Some herbicides remain active in the soil for a significant period, stretching from weeks to months to years, depending on soil type, soil moisture, soil temperature and other factors, as well as the sensitivity of the crop (see Table 26).

Herbicide residues can also be introduced through the application of straw and manure. As well, residues can move in soil water or be introduced via irrigation or runoff.

Table 26 outlines the residual longevity in soil of various commonly used herbicides based on normal use rates and average soil conditions.

Table 26. Common herbicides and their approximate lifespan in soil

Chemical active ingredient*	Approximate longevity in soil**
Atrazine	2 years +
Linuron	1 year +
Metsulfuron methyl	2 years
Amitrole	2 - 4 weeks
Imazamethabenz-methyl	2 years
Triallate	1 season
2,4-D	10 weeks
Dicamba	Check label
Napropamide	1 year +
Ethalfluralin	1 year +
Triallate + trifluralin	1 year +
Chlorsulfuron	4 - 5 years
Trifluralin	1 year +
Metribuzin	1 year
Clopyralid	2 years
Linuron	1 year +
S-metalochlor + atrazine	2 years +
Pyrazon	1 year
Simazine	2 years +
Terbacil	2 years
Picloram + 2,4-D	3 - 5 years
Bensulide	1 year +
Diuron	2 years +

* This is not a complete list of products.
** Chemical lifespan in the soil is influenced by factors such as moisture, microbial decomposition, temperature, etc.

Insect pest management

Insect pests can damage, weaken or kill crops through feeding during their various life stages. Insects can pose a significant threat to the success of a vegetable crop. Managing insect pest populations through a combination of methods is preferred over the application of a single product to kill everything. Take care to reduce the risk of damage from insecticide applications to non-target species and the environment.

The correct identification and quantification of insect pests are critically important for making proper management decisions. Proper timing and application of treatments are also important to ensure success. Insects have stages when they are more susceptible to control.

General management recommendations for specific insect pests are listed under each crop in the Vegetable Production Recommendations chapter. You can also consult specialists for assistance with the identification and management of insect pests.

Specific recommendations for registered chemical products are not presented in this manual due to regular changes in registration and the availability of product. Consult product labels for specific rate and application details. Consult provincial government or chemical company resources for assistance with product selection.

The following are general guidelines for controlling insect pests of vegetable crops:

- Practice crop rotation whenever possible. Growing crops not susceptible to the same pests prevents the buildup of serious pests.
- Practice field sanitation (destruction of crop debris, good weed control, cull pile management) to help prevent insect pests from completing some stage of their life cycle or from being protected during the winter.
- Time planting and harvest to avoid peaks in insect populations.
- Examine plants frequently throughout the growing season to detect insect infestations in their earliest stages. The best control is achieved and crop damage is minimized when insect pests are controlled when the insects are young and the pest population is small.
- Carefully select products to control the target species, with an effort to minimize the effect on non-target species.
- Consider the crop stage when determining insecticide application rates. Based on the product label specifications, use the lower rates and volumes when plants are small, and use the higher rates and volumes as the plants grow larger. For best results, spray both sides of the leaves. Do not exceed maximum application rates and any listed yearly maximums.
- Know the economic damage thresholds. There is no point spraying insects that are not pests. There is also no point spraying pests that are not damaging the crop due to their limited numbers, a non-susceptible crop growth stage or if pre-harvest intervals will be exceeded, etc.

Common insect pests of vegetable crops

Some insect pests have the potential to damage a wide spectrum of the vegetable crops commonly grown in Canada. These pests are typically managed in the same way for all vegetable crops.

Aphids

Aphids are small, soft-bodied, piercing/sucking insects. A number of different aphid species can damage vegetable crops. See Figure 6 and the individual vegetable crops in Chapter 6 for more discussion.

Blister beetles

Crops attacked
Asparagus, beet, beans, cabbage, carrot, celery, chicory, Chinese cabbage, corn, eggplant, leafy greens, okra, onion, pea, pepper, potato, pumpkin, radish, squash, tomato and turnip

Description/life cycle
Blister beetles are occasional pests of many vegetable crops. These beetles generally are black (*Epicauta pennsylvanica*), grey (*E. fabricii*) or metallic colours (*Lytta nuttalli*). They range in length from 10 mm (0.4 in.) (*Epicauta species*) to 30 mm (1.2 in.) (*Lytta*). Blister beetle larvae feed on grasshopper egg pods, but the adults are foliage feeders, although they sometimes prefer to feed on blossoms.

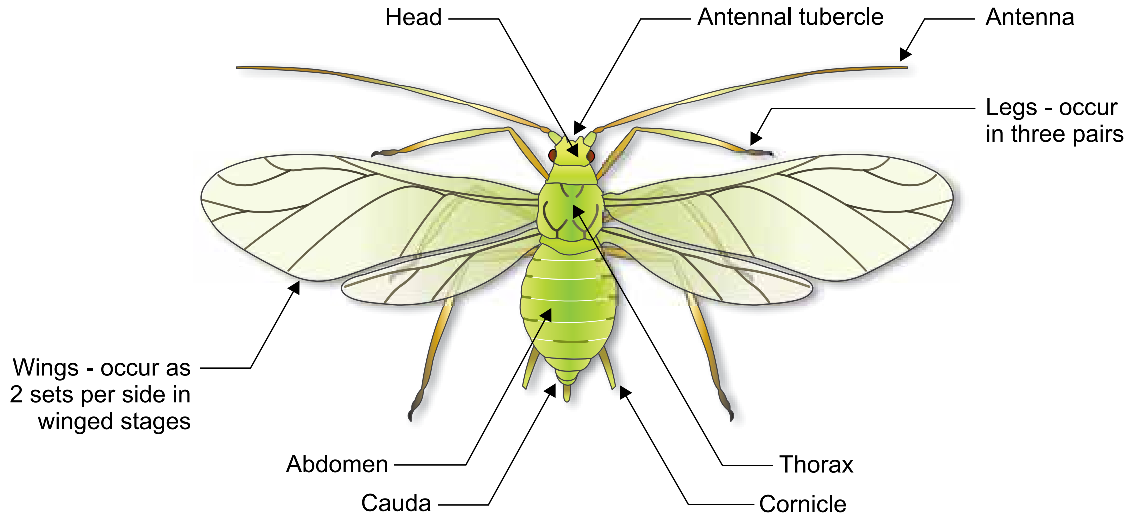


Figure 6. Diagram of generalized aphid body structure

Description/distinctive features of various aphid species

Common name	Latin name	Colour	Body form	Antennal tubercles	Cornicles	Cauda	Other feature(s)
Green peach aphid	*Myzus persicae*	Light yellow-green to pink	Egg/ teardrop-shaped	Inward pointing	Unevenly swollen	Short	Leg and cornicles same colour as body; antenna long or longer than body
Potato aphid	*Macrosiphum euphorbiae*	Yellow-green or pink	Elongate/ wedge-shaped	Pointed outward	Long, slender	Long and pointed	Highly mobile; long legs
Buckthorn aphid	*Aphis nasturtii*	Lemon-yellow to green	Small, flat; egg-shaped	None	Short	Short	Antennae shorter than body; one of smallest aphids
Pea aphid	*Acyrthosiphon pisum*	Light to dark green	Pear-shaped	Divergent (outward pointing)	Long and Slender	Well-developed	Long, slim legs, antennae, cornicles; narrow dark bands at segments of antennae
Asparagus aphid	*Brachycorynella aspargi*	Green	Elliptical; egg-shaped	Lacking; nearly flat head	Small, mammiform	Moderately-long and parallel-sided	Covered with mealy-grey wax; very short antennae
Lettuce aphid	*Nasonovia ribisnigri*	Olive green to orange to pink	Egg-shaped	Not strongly converging (inward pointing)	Cylindrical with distinctive ring-like incision	Finger-shaped with 7 hair-like setae	Long antennae; distinct dorsal pattern on body; dark at joints
Corn leaf aphid	*Rhopalosiphum maidis*	Greenish-blue to black	Small, pear-shaped	–	Dark, short to medium length	Dark and projecting	Horseshoe or crescent-shaped patch on back of abdomen

Adult blister beetle (*Epicauta vittata*)
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Damage/symptoms
Adults feeding on blossoms results in reduced yields. Heavy feeding by groups of blister beetles has the potential to wipe out crops like beans. Feeding damage by adult blister beetles is often irregular within the field, with some areas heavily damaged while others are entirely missed. This irregular damage may make scouting a challenge, but once the infested areas are located, blister beetles are a good candidate for spot treatments.

Control/management
Blister beetles can be easily managed by the foliar application of common insecticides. There are no known cultural or biological management schemes for this pest.

Cutworms

Crops attacked
All crops

Description/life cycle
Hundreds of cutworm species attack crops. Cutworms tend to curl up when disturbed. Most cutworms are nocturnal, resting in the soil during the day and feeding underground or just at the soil's surface in the evening. There are also "climbing" cutworms, such as the variegated cutworm (*Peridroma saucia*); these cutworms feed on the foliage rather than at ground level. Climbing cutworms tend to be present later in the season, often when fruit is on the plant.

Typically, only one generation of cutworms is produced per year. Eggs are laid in the fall with the tiny larvae hatching out in the spring. The larvae grow larger as they mature. They feed on the crop or nearby weeds until late June, when they start pupation in the soil. Adult moths emerge in July or August. Adults are the well known "miller moths," which are attracted to lights in mid-summer.

Damage/symptoms
Most cutworms damage plants during the seedling stage. They clip the stems, giving the appearance of patchy emergence to weak stands. Scouting at night or digging in the top of the soil will reveal the pests.

Climbing cutworms are classic defoliators, feeding on the leaves. These cutworms may be visible during daytime visual scouting, though they tend to prefer feeding at night.

Control/management
Chemical control is the standard approach to cutworm management. Scouting followed by spot treatments is recommended because the distribution of cutworms within fields is often uneven.

Red-backed cutworm
Photo: Robert Spencer

The most effective control is obtained by applying the insecticide in late afternoon or early evening just before the cutworms come out to feed. Many insecticides have short residual activity and will only be effective if the pests come in contact with them shortly after application.

Grasshoppers

Crops attacked
Asparagus, bean, beet, cabbage, carrot, cauliflower, celery, corn, cucumber, lettuce, onion, pea, potato, radish, squash and tomato

Description/life cycle
Grasshopper populations are often highly variable in space and time. Many grasshopper species prefer to feed on crops other than vegetables, but they can damage vegetable crops if their preferred food sources become scarce. Dry conditions favour grasshoppers, so they tend to be more of a significant problem further south and west in the Prairies.

The economically damaging species of grasshoppers lay their eggs in the fall, and these eggs hatch in the spring. Rainfall in the fall during egg deposition or in spring during the nymphal hatch can significantly reduce population numbers. Nymphs go through several developmental stages, eventually becoming reproductive adults in August. The nymphs appear similar to the adults but do not have wings. Feeding damage occurs at all stages.

Adult grasshopper
Photo: Manitoba Agriculture, Food and Rural Development

Damage/symptoms
Grasshoppers are defoliators, preferring to feed on foliage. The chewing damage is clearly visible along with the nymphs and adults. Damage is typically worse along field margins.

Control/management
Management through the application of pesticides is best achieved early in the season when nymphs are young. The treatment of headlands and field margins can be highly effective. Mechanical tillage in the fall can expose egg masses and reduce their winter survival.

Mites

Crops attacked
Bean, beet, cantaloupe and other melons, carrot, celery, corn, cucumber, eggplant, parsley, pea, pepper, squash, tomato – most often attacked, tomato, bean and cucurbits

Description/life cycle
Mites are not true insects. They are more like spiders, having eight legs. The two-spotted spider mite (*Tetranychus urticae*) is the most likely mite to be attacking vegetable crops on the Prairies, but other species may also be an issue. Adult mites are typically only 0.4 to 0.5 mm (0.016 to 0.02 in.) long when mature. They are most easily detected by the presence of their webbing, which is found on the underside of affected leaves.

Mites go through four life stages (egg, larva, nymph and adult). The rate at which they progress through these stages depends on temperature. Multiple generations are possible in a growing season.

Damage/symptoms
While not typically a problem in most years, mites can be a late-season problem especially during hot, dry years. Mites feed on the underside of the leaf surface, sucking out the sap. The undersides of leaves will appear flecked or bronzed. This is a significant problem in crops where the leaves are sold. Mites do not affect fruit directly, but extensive mite damage to the foliage can reduce crop productivity and quality. Mite infestations typically occur at field margins first.

Severe spider mite infestation on strawberry leaves
Photo: Robert Spencer

Control/management
Natural enemies often keep mite populations in check. However under suitable weather conditions, populations can build up extremely rapidly (a single generation in 5 to 7 days under optimal conditions), overwhelming the natural enemies with sheer numbers.

Insecticide treatments to control other pests (such as cucumber beetles) may inadvertently kill the beneficial organisms that normally keep mite populations in check. Therefore, if you must treat for beetles, watch for subsequent mite problems.

Because mites are not insects, most insecticides are not completely effective at mite control. Most insecticides only kill the adult mites, leaving the eggs and soil stage nymphs unharmed. Multiple insecticide treatments may be required to effectively control an outbreak population. Spot spraying may be effective because mites are not overly mobile. The use of miticides can reduce the effects on non-target insect species.

Wireworms

Crops attacked
The seeds and roots of all crops are susceptible to wireworm damage, but the effect on plant stand and crop value is greatest for widely spaced, large-seeded crops like beans, corn and potatoes.

Description/life cycle
Wireworms are the larval stage of click beetles (Elateridae family). The adults are narrow, brown to black beetles from 5 to 20 mm (0.2 to 0.79 in.) in length. Larvae are pale creamy to rusty brown, slender and cylindrical, with three legs near the head. The larval stage can last 2 to 5 years depending on the species and field conditions. Mature larvae range in length from 20 to 30 mm (0.79 to 1.18 in.). Larvae can survive extended periods without feeding, meaning that they can survive for extended periods between crops. Larvae move within the soil to feed on roots, seeds or tubers, in the case of potatoes.

Wireworms will also move in response to gradients in temperature and moisture within the soil profile. Wireworms are typically found near the soil surface in the cool conditions of spring and fall. In spring, this position brings them in contact with the newly planted seed, while in the fall, they come in contact with developing potato tubers.

Damage/symptoms
Wireworm damage is associated with feeding by the larval stage. The larvae are attracted by the carbon dioxide produced by germinating seeds or seed potatoes. Wireworm feeding can cause the injury or death of seedlings leading to an unhealthy and spotty crop stand. The extent of damage depends on the size of the wireworms, the population and the field conditions (temperature and moisture).

Larval stage of wireworm
Photo: Robert Spencer

In the fall, wireworms move back toward to the soil surface where they damage potato tubers. Wireworm damage to potato tubers shows up as small diameter holes running from the surface into the interior of the tuber. In some cases, the wireworms will come through the far side of the tuber. Timing of the damage can be discerned based on the degree of wound healing that has occurred. Wireworm feeding on potato tubers causes little actual yield loss but can significantly reduce tuber quality, often rendering them unmarketable.

Control/management
A long crop rotation out of the most preferred host crops may help control wireworms. Avoid planting vegetable crops on newly turned sod because wireworm populations can be quite high in sod. Alfalfa in rotation may aid in reducing populations but must remain in rotation for 3 to 4 years. Canola is another non-host crop that might be used in rotation.

Chemical control of soil-inhabiting pests like wireworms is difficult. Limited insecticidal control is available. Some registered seed treatments are available for potatoes and for cereal crops. In-furrow treatments are also available for use in potatoes.

Bee poisoning

Pollinating insects, especially honeybees, are absolutely required for pollination and fruit set for vine crops like cucumbers and melons. While not absolutely required, insect pollination may also improve yields and fruit quality in peas, beans, peppers and eggplants. An insecticide application that is harmful to honeybees is a concern to vegetable growers.

To help prevent bee poisoning, consider using some or all of the following practices:

- Do not spray any flowering crop on which bees are foraging. If insecticides must be applied, spray in the early morning or evening when bees are not foraging. Bees usually do not forage at temperatures below 13°C (55°F).
- If it is necessary to apply an insecticide that is poisonous to bees, notify neighbouring beekeepers, so they may protect their bees.
- Do not apply insecticides on windy days because drift toward any nearby beehives or natural areas that provide habitat for native bees may cause bee poisoning.
- Ground applications of insecticides are generally less hazardous than aircraft applications, and there is usually less drift.
- Choose pesticides that are least hazardous to bees. Sprays are less toxic than dusts. Emulsifiable concentrate formulations are less toxic than wettable powder formulations.

Most organophosphate and carbamate insecticides are highly toxic to bees. A number of insecticides and their relative toxicity to bees are listed in Table 27.

Disease management

Compared with most other major vegetable production areas, the Canadian Prairies are relatively free of serious diseases on vegetable crops. However, severe disease outbreaks can occur, and growers should be familiar with preventive and control measures.

Seed treatments, sterilization of transplant soil and equipment as well as disinfection of storage and associated equipment can all play important roles in the prevention of diseases both in the field and in storage.

Specific disease management recommendations for individual crops are listed in the Vegetable Production Recommendations chapter. For more detailed information on disease management in a specific crop, contact provincial specialists or consult available resources.

Here are general recommendations for managing diseases:

- Use sterile greenhouse media, fumigation or steaming of seedbeds, fungicidal soil drenches, proper cultural practices (especially relating to watering) and seed treatment fungicides to prevent damping-off of seedlings.
- Use hot water or chemical treatments to eliminate some seed-borne diseases.

Table 27. Relative toxicity of some insecticides to honeybees*

Very toxic Do not apply to flowering crops or weeds		Toxic Apply only during late evening or early morning	Low toxicity or limited effect (if applied correctly)
Abamectin	Malathion	Pirimicarb	*Bacillus thuringiensis* (Bt)
Acetamiprid	Methamidophos	Pymetrozine	Chlorantraniliprole
Azinphos-methyl	Methomyl	Trichlorfon	Dicofol
Carbaryl	Naled		Flonicamid
Carbofuran	Novaluron		Insecticidal soap
Chlorpyrifos	Oxamyl		Horticultural oils
Clothianidin	Permethrin		Tebufenozide
Cypermethrin	Phosalone		
Deltamethrin	Phosmet		
Diazinon	Spinetoram		
Dimethoate	Spinosad		
Endosulfan	Spiromesifen		
Imidacloprid	Spirotetramat		
Lambda-cyhalothrin	Thiamethoxam		

* Notes: Unusually low temperatures at the time of application may cause insecticides to remain toxic up to 20 times longer than during warm weather. High temperatures in the early morning or late evening may extend active foraging by bees and adversely affect bees on treated crops. Consult pesticide labels or chemical company representatives for specific information on bee toxicity for products not included in this list. This is not a complete list.

- Rotate crops so that those susceptible to the same diseases are not planted year after year in the same or nearby fields.
- Destroy crop debris, manage volunteers and cull piles to reduce the probability of residue-borne diseases in subsequent crops.
- Isolate and rogue (remove) diseased plants and control insect vectors to minimize the spread of viral diseases.
- Use disease-resistant or tolerant varieties where possible.
- Use fungicides and bactericides for the prevention of foliar diseases.

General diseases

Seedling diseases

For information on diseases like seed rots, damping-off and seedling blights, see the Disease Management section in the Transplant Production chapter.

Root rots

Crops attacked

A wide range of vegetable crops may be attacked by root rot pathogens.

Description/disease cycle

Root rot pathogens include *Pythium*, *Rhizoctonia*, *Fusarium*, *Phoma*, etc. They are soil-borne, surviving as mycelium, sporangia or oospores for varying lengths of time, depending on the species. They can also survive on plant roots or organic matter if conditions are suitable. Young plants, tender plant parts and weakened plants are typically attacked. The pathogens may attack individually or as part of a disease complex.

These pathogens flourish in cool, wet conditions, particularly in waterlogged or poorly drained soils. Short-term over-application of water can also cause root rots.

Damage/symptoms

Symptoms can occur pre- or post-emergence, in both annual and perennial crops. In some cases, foliar symptoms may resemble symptoms of other seedling diseases, including wilting, stunting, yellowing and collapse of plants. Leaves may be reduced in size, and plants will generally lack vigour and may appear to be nutrient deficient or lacking for water. Plants will not respond to additional applications of water.

Root rot of seedlings; note damaged and discoloured root and stem tissues at base of plant as well as reduced number of roots
Photo: Howard F. Schwartz, Colorado State University, Bugwood.org

Roots will typically be reduced in number and may have light brown, depressed, water-soaked lesions that expand over time. Existing roots may be brown or black, and rootlet development is sparse or nil.

Control/management
Ensure that growing areas are suitable, with well drained soils to encourage healthy, rapid plant growth. Avoid overwatering and waterlogging. Plant into warmer soils, and use clean seed and healthy, well-rooted transplants. Remove infected plants as soon as possible. Follow good crop rotations. Provide adequate fertilizer and water for plants to grow. Registered seed treatments and foliar fungicides (including transplant drenches) may be appropriate.

Seed treatment
Seeds are commonly treated with a fungicide and/or an insecticide to help protect them against seed- and soil-borne diseases and insect pests in the soil during germination and early growth. Certain kinds of seeds also require special treatment to kill parasitic fungi or bacteria that may be present in or on the seed, unless the seed has already been treated by the seed company.

For methods of application and quantities of pesticide to use in seed treatments, see the label directions on the pesticide container. Many seed treatments must be made by a licensed applicator. Seed treatment with an insecticide-fungicide mixture should be done not more than 3 months before planting.

Seed treated with either fungicides or insecticides must not be used for food or fed to livestock. It should be labelled to indicate what it has been treated with.

Abiotic problems

Not all plant problems are caused by biological agents like fungi, bacteria or insect pests. Many issues can be traced to abiotic (physical) causes. For example, weather conditions such as drought, flooding, frost, winds, lightning or excessive heat can cause plants to be damaged, stunted or stressed. Poor or excessive levels of light or nutrient availability, mechanical injuries or improper chemical use can also cause abiotic issues.

An abiotic problem can be difficult to diagnose if it is not identified quickly because secondary decay organisms can exploit the damage to the plant and cause decomposition. Keep detailed records of production activities (irrigation, pesticides, fertilizers, etc.), weather conditions and any changes in cultural practices to help in determining the specific cause of a problem.

Spray equipment

Pesticides can be applied using various types and sizes of equipment, ranging from backpack sprayers through to large boom sprayers. Match the equipment with the type of application, considering the area to be treated, nozzles, spray pressures, etc. Ensure that proper procedures are followed, spray equipment is properly calibrated and adjusted, and appropriate safety equipment is used.

Spray nozzles

Spray nozzle tips function in three ways:

- break up liquid pesticides into the fine droplets required to provide full coverage of the crop
- form a spray pattern
- propel the spray droplets in the proper direction

Spray drift can be minimized by selecting nozzles that produce the largest droplet size while providing adequate coverage of the target area at the intended application rate and pressure.

Nozzle tips are available in brass, aluminum, nylon, stainless steel, hardened stainless steel (HSS) and ceramic materials. Brass tips have a low initial cost; however, they wear rapidly if wettable powder pesticides are sprayed. Nozzles made of nylon, stainless steel and HSS are most commonly used.

Plugged nozzle tips should be cleaned with a soft bristled brush or a toothpick. For nylon nozzle tips, use only a soft brush because a toothpick can damage the orifice. Worn nozzle tips may have a higher spray output or uneven spray patterns and should be replaced.

A number of different nozzle tips are available. Some common types and their spray pattern characteristics and main uses are listed in Table 28.

Flat fan nozzles can produce spray angles of 65°, 80° and 110°. Nozzle tips with larger spray angles must be placed closer to the soil or crop to reduce the risk of spray drift.

The selection of nozzle tips also depends on the desired spray volume output and droplet size. For a number of herbicides, small droplet sizes with liquid spray volumes of 20 to 40 L/ac. (50 to 100 L/ha) are required. For other products, the recommended spray volume can range up to 445 L/ac. (1,113 L/ha). Since herbicide efficacy is affected by spray volume, use proper-sized nozzle tips.

For more details on nozzle tips and information on pumps, booms, spray overlap, controlled droplet applicators and sprayers in general, consult provincial resource materials or contact equipment suppliers.

Band spraying

Band spraying involves the application of pesticides to a specific area of the field, as opposed to the treatment of the entire field. This method might involve applying product in a strip or band, either over the specific row, along the base of the plants or where the problem is, rather than the entire field. The use of band spraying reduces the total amount of pesticide applied, which reduces costs and the potential environment impact.

Table 28. Nozzle types and their spray patterns and uses

Nozzle type*	Spray pattern characteristics	Main use
Standard flat fan	Uniform when boom is at proper height; best for broadcast spraying	Herbicides; insecticides
Even flat fan	Not uniform for broadcast spraying; good for band spraying	Herbicides
Extended range flat fan (low and high pressure)	Uniform pattern; droplet size depends on pressure	
Twin-orifice fan	Two spray patterns: angles 30° forward and 30° backward; small droplets	Post-emergent contact herbicides; insecticides; fungicides
Off-centre fan	Not as uniform as flat fan nozzle; useful to extend coverage on headlands and fences where boom cannot reach	Herbicide application for special situations
Flooding fan	Not as uniform as flat fan nozzle; low drift	Liquid fertilizers; some herbicides; soil-applied insecticides
Full (solid) cone	Not uniform when used on a boom; best for directed spraying	Soil-incorporated herbicides
Hollow cone	Not uniform when used on a boom; best for directed spraying; higher drift potential	Insecticides; fungicides
Turbo flat fan	Less drift; good pattern uniformity	Post-emergent products
Flood	Not as uniform as fan	Suspension fertilizers; soil-incorporated and pre-emergent herbicides; flood-applied product
Air induction	Large droplets	

* Other nozzle types may be available. Consult a supplier for more information.

Band spraying can be done with one, two or three nozzles per row. One nozzle per row may be used when the plants are small, but more nozzles and higher spray volumes are required to achieve thorough coverage of larger plants or if more spray volume is needed. An even flat fan spray nozzle or a hollow cone nozzle should be used for band spraying. Even spray nozzles are generally preferred for herbicides and hollow cone nozzles for drenching with insecticides.

Calculating the application rates for band spraying can be confusing. One must consider the concept of total acres (whole area of the field) relative to treated acres (area actually treated in the band).

To calculate the amount of pesticide to be used, use the following equation:

(broadcast rate per acre) x (band width ÷ row width)

Example:

6 L/ac. (15 L/ha) is to be applied to a 10-cm band with 60-cm row spacing

then, 6 L/ac. x 10/60 = 1 L/ac. is required for each acre treated in 10-cm bands with 60-cm row spacings

Several band spraying arrangements are available.

Drenching

Drenching involves the application of a pesticide in a sufficient volume of water so that the pesticide washes off any plants and into the soil where it saturates the soil profile to a significant depth.

Drenching is most commonly used to apply insecticides for managing soil-inhabiting insect pests such as cutworms and root maggots. It is also common for applying fungicides that target pathogens that attack plant roots or soil- or seed-borne pathogens.

In a drench application, products are typically applied in a band, with flood nozzles providing the large water volumes required.

Drop nozzles

Drop nozzles are recommended for certain pesticide applications, typically where the objective is to direct the pesticide spray away from the crop. For example, 2,4-D amine must be applied when corn exceeds 15 cm (6 in.) in height. If the 2,4-D comes in contact with the crop, particularly the leaves, the crop can be killed. Therefore, drop pipes are attached to the spray boom by replacing nozzle outlets.

These drop pipes extend into the crop canopy, delivering the 2,4-D to the area between the crop rows, while minimizing the risk of having the spray contact the leaves. The drop pipe should have a double nozzle housing so that two nozzle tips per drop pipe can be installed. This structure provides two nozzles for each crop row on either side of the drop pipe.

Pesticide storage and shelf life

Most pesticides are designed to last for 2 years or longer when properly stored by the user. Proper storage involves cool (but not frozen), dry conditions. Wettable powders stored at cool temperatures and low humidities will be stable for at least this period of time. Bags should be tightly sealed during storage. Liquid formulations generally do not last as long as powders, but if kept sealed and away from temperature extremes, they should last for 2 years.

It is a good idea to purchase only the amount of pesticides you expect to use within 2 years. Consult specific pesticide labels for proper storage guidelines for each product.

Pesticide handling and safety

Pesticides are toxins specifically designed to disrupt the normal metabolic functions of the target species. Many pesticides can be harmful to humans. Therefore, take every precaution to protect both applicators and those who may come in contact with or consume the crop after application.

Use only registered products at recommended rates under recommended conditions. Carefully follow the recommendations for re-entry and pre-harvest intervals. Wear proper personal protective equipment when handling, mixing, applying and cleaning up after pesticide application as well as upon re-entry into the field. Consult pesticide labels for appropriate pesticide handling practices and pesticide safety information.

Pesticide regulations

The *Pest Control Products Act* of Health Canada's Pest Management Regulatory Agency (PMRA) governs the registration and use of all pesticide products in Canada. These regulations are in place to ensure the safety of both producers and consumers and to minimize risk associated with the application of pesticides (e.g. environment, food safety, health, etc.)

Consult product labels when selecting pesticides for your crops. Do not apply unregistered products. Apply products according to label directions.

For more information, see PMRA in the Resources section in the Appendix.

BUSINESS MANAGEMENT

Business Management

Introduction

Commercial vegetable production should be viewed as a business first and as a farming enterprise second. This chapter looks at several aspects of a successful vegetable production business including labour, food safety, organic production, risk management and marketing.

Labour

Vegetable production is labour-intensive, regardless of scale. Much of the labour is temporary or seasonal. Many activities must be completed by hand, and multiple steps are required from before seeding through to sale. Equipment use is an option for some activities, but can add significant expense and still requires operators.

Currently, in most areas, the demand for labour far outstrips the available supply. Competition for labour with other industries (e.g. oil and gas) is intense and has driven up the cost of labourers. Producers may hire local workers or use national labour programs to find workers. Many growers have turned to temporary foreign workers to meet the bulk of their labour needs.

Sourcing foreign labour can mean the difference between success and failure for many operations. However, foreign worker programs require a significant amount of paperwork, and there are many rules and regulations to follow. Assistance with sourcing labour is available from provincial governments and from the national program offices. See the Resources section in the Appendix for contacts.

Risk management

Vegetables are sensitive to damage from a range of environmental factors, including frost, hail, wind, etc. Depending on the location and the province, risk management programs may exist to assist in protecting producers from economic loss due to any of these factors. Consider every option to buffer your vegetable operation from loss.

Food safety

Recent cases of food-borne illness have raised consumer awareness about contaminated food. Most retailers require their suppliers to provide them with assurance that they are enrolled in a food safety program.

To ensure that producers maintain a high level of consumer confidence, the Canadian Horticultural Council (CHC) has developed an On-Farm Food Safety (OFFS) Program (CanadaGAP) for fruit and vegetable producers and packers. There are other food safety programs that retail buyers may require suppliers to enrol in, but the CHC CanadaGAP program is accepted by most retailers in Canada. Please check with your buyer to ensure you are enrolled in the correct program.

See the link for CHC CanadaGAP in the Resources section in the Appendix for more information.

CanadaGAP is designed to help producers and packers implement effective food safety procedures. Eight crop-specific safe production and handling manuals were written by the industry. The manuals were reviewed for technical accuracy by the Canadian Food Inspection Agency (CFIA), along with experts from provincial governments, and then the manual content was piloted on farms to ensure that the manuals were practical.

The eight manuals, based on HACCP (Hazard Analysis and Critical Control Point) principles, ensure that participants implement Good Agricultural Practices (GAPs). These manuals cover the following:

1. Potatoes
2. Bulb and Root Vegetables
3. Fruiting Vegetables
4. Leafy Vegetables and Cruciferae
5. Asparagus, Sweet Corn and Legumes
6. Greenhouse Production
7. Tree and Vine Fruit
8. Small Fruit

The CanadaGAP program is administered and maintained by the CHC. The program can be audited, and the farms that pass the audits are then certified. For more information on the CanadaGAP program, contact the CHC or your local vegetable growers' association.

Please note, in some provinces, scaled-back versions of the CanadaGAP program may be available to raise the awareness of the principles of on-farm food safety and to allow producers to transition to CanadaGAP over time.

Basic principles of food safety

Here are five key practices for providing safe vegetables:

1) **Employee training**: Farm owners and managers must educate all staff about the potential for biological, chemical and physical contamination of produce from the field through every stage until the commodity leaves the farm. Employees must be aware of their role in preventing contamination of the vegetables. For example, the employees must know that if they are ill, they must inform their employer, as certain pathogens that cause human diseases, like the hepatitis A virus and the bacterium *E. coli* O157:H7, can spread on contaminated produce. Employee training records must be kept.

2) **Water quality and sanitation**: Water is used for irrigating crops as well as for washing and fluming (carrying vegetables in a water-filled channel) the harvested product. Potable water is required for all cleaning, washing, fluming and cooling steps as well as for the personal hygiene of the workers. The risk of water contamination depends on the source and how the water is stored and used. If using on-site water sources (surface water, wells or cisterns), producers must understand how to treat the water and how to maintain and monitor its quality. Remember that ice is part of the water quality system.

3) **Good Agricultural Practices (GAPs)**: Producers are already performing many of the GAPs identified in the CanadaGAP program and other on-farm food safety programs. Most of these practices are just good common sense. These practices include assessing production sites for potential sources of contamination (e.g. human pathogens, pesticides, heavy metals, etc.); applying fertilizers, manures and composts responsibly; maintaining a pest control program; and calibrating and maintaining equipment regularly. GAPs include inspecting transport vehicles for cleanliness and potential sources of contamination, storing packaging materials properly, managing waste responsibly, maintaining storage cleanliness, maintaining the post-harvest cold stream, etc.

4) **Personal hygiene**: Clean, well maintained toilet and hand washing facilities must be available to help prevent employees from being a source of biological contamination of the produce. Lunch and coffee room areas must be provided away from the production area. As well, keep a fully stocked first aid kit on hand.

5) **Good record-keeping and traceability**: Because any OFFS program can only minimize risks, one of the goals of a good program is to ensure that the vegetables could be quickly traced back to the point of

origin should a food safety event occur. An identification system must be in place for all lots. Timely and accurate records must be kept.

Large retailers will demand that their suppliers have implemented an OFFS program and adhere to it. All vegetable producers (large or small) should follow an OFFS program.

Organic production

Organic crop production occurs when crops are grown under a production system that promotes soil health, biodiversity and sound environmental practices without the use of synthetic fertilizers, pesticides and growth regulators. In broader terms, it is crop production that seeks sustainable production with minimal disruption to natural systems.

Principles of organic production:

- ecological soil management that relies on building humus levels through crop rotations, recycling organic wastes and applying balanced mineral amendments
- no synthetic inputs such as chemical fertilizers, pesticides and growth regulators
- emphasis on integrated pest management (IPM), including cultural and biological controls
- emphasis on minimizing reliance on off-farm inputs

Organic certification generally comes under the auspices of the *Canada Agricultural Products Act* and the Organic Products Regulations, which are enforced by the Canadian Food Inspection Agency (CFIA). The National Standard of Canada for Organic Agriculture outlines the standards and practices that participants must adhere to. In some jurisdictions, provincial regulations are in place and may be applied.

Participants must undergo a three-year phase-in period before becoming certified, which is accomplished through third-party certifying bodies. Annual audits and inspections are carried out to ensure that participants conform to organic standards and are required to maintain certification. There is a cost associated with organic certification.

Organic production practices are not exclusively limited to "certified organic" producers. Producers may follow practices without certification, but cannot claim to be organic.

Marketing

A key factor in achieving a profitable vegetable operation is having a well thought-out marketing plan. Markets for your vegetable crop need to be clearly established before planting the crop. This plan is especially important for highly perishable types of vegetables as the market window for these crops is limited.

Many vegetable operations fail due to a lack of market development or marketing skills. A potential grower will need to spend considerable time and effort in market research to create an effective marketing plan.

In developing a sound marketing plan, the following questions should be answered:

- What crops and which varieties should I grow?
- To whom, where and when will I sell the produce that I will grow?
- How much demand is there for the crops I am considering?
- What are the market windows for these crops?
- How much of these crops should I produce?
- How much will it cost me to produce and market these crops?
- What are the risks associated with the production and marketing of these crops?

Do not underestimate the importance of this step in planning. Your answers will not only help you refine your marketing plan, they may also cause you to revise your business plan.

Marketing channels

Vegetables can be marketed in several ways, depending on the producer's preference as well as the available markets and demand in an area for a product. The scale of the operation can also influence how a particular product is marketed. Some producers may use a range of marketing channels to address different volumes of product at different times of year or according to their preference.

Depending on the province, rules or regulations may restrict some types of marketing or may limit the number or types of crops that may be grown for sale outside of certain market systems. Consult with your provincial specialists for direction on rules and regulations.

Direct markets

With direct marketing, producers typically market directly to consumers. This type of marketing is done on a local or regional scale rather than on a provincial or national scale.

With direct marketing, producers may sell their product to consumers on their farm (U-pick operations or on-farm stores), or they may harvest and transport their product for sale to the consumer, either via a Farmers' Market or a small store. Producers can also set up community shared agriculture (CSA) operations, where they deliver to consumers in regular food boxes or some other way, using a share system. Producers may also sell directly to restaurants, caterers or other buyers.

Direct market producers tend to offer a wide variety of crops to their buyers. Producers have control over the prices they charge and typically focus on quality and a relationship with their consumers (such as the "buy local" movement), rather than competing against larger scale commercial growers based on price.

Wholesale and retail markets

Selling into retail or wholesale markets is typically used for larger volumes of specific products, with producers typically specializing in a smaller selection of crops, although they may produce multiple varieties of the same crop. Product is typically sold to a central point, from which it may be sold to retail stores or may be repackaged before sale. Wholesale producers do not have direct contact with consumers and typically sell higher volumes of product to make up for lower prices.

Improving market share

Vegetable producers face competition from local producers, from producers in other regions and countries and from other commodities. To survive, producers must market their produce effectively. Catching the consumer's eye and increasing demand can be achieved through elements of marketing:

- packaging
- pricing
- promotion
- product quality

Producers can also increase demand and/or revenues by adding value to their existing products through processing or by combining their fresh produce sales with other offerings (agricultural tourism, etc.)

Packaging

Product packaging has many purposes, including facilitating the handling and display of the product. It may also help preserve the product's quality and cleanliness. Packaging can convey information about the product or the producer. Some types of packaging are more appropriate for certain crops than others, and specific rules or regulations may exist for specific crops. Each of these purposes needs to be considered when selecting packaging.

Packaging is also a simple way to increase the appeal of a product. Producers can use a wide range of materials for packaging, adjusting how a product is presented both in terms of the product's look and the size or volume of the offered product.

Consider the legal requirements for packaging and labelling, ensuring that an appropriate amount of information is provided on the package. Where a product is marketed can affect the labelling and packaging requirements. Consult the appropriate specialists in your province when setting up your packaging.

Pricing

Setting prices for harvested products can be a complex process. Consider all the costs involved in the production of the products when setting their price. These costs include input costs (seed, fertilizer, water, pesticides, etc.) as well as labour, equipment, storage, marketing, transportation, etc.

Labour costs include both hired labour and the labour of the producer/owner. Risk and opportunity costs should also be covered in the price. Accurately track production costs to set a fair and appropriate price for your products. Selling a product at a breakeven cost can increase sales, but will not be sustainable in the long run.

Product quality

Ensure the products you sell are of top quality because consumers will consistently pay for a product they see as being fresh, healthy and of good quality. Quality product is easier to sell than inferior product. Failure to deliver a quality product can result in the loss of customers. Quality is a subjective term; therefore, producers need to determine what their customers want. An unsatisfied customer is the worst advertising any business can have. Remember the old adage: "the customer is always right."

Value adding

Producers can add value to their fresh product by packaging it differently, such as grouping it with other products. Alternatively, the value of a product can be enhanced through processing, such as by making pickled products, spreads, pastes, salsas, etc.

Producers must ensure that these lightly processed value-added commodities are produced according to health regulations and conform to all other applicable regulations. Processed products come under different packaging and labelling regulations than fresh vegetables.

Associations

Membership in industry associations can provide producers with many tangible benefits at minimal cost. The benefits of working with other growers and industry stakeholders may include assistance with marketing and advertising, whether in terms of exposure to potential clients and customers or in increasing market demand for industry products as a whole.

Additionally, associations may serve a role in lobbying government or other bodies on industry issues, or they may provide training and networking opportunities for their members. Associations can also support and direct research within the sector, which can directly benefit producers' profitability and success.

Consider what each individual association has to offer. Participating fully in your chosen associations will increase the value that comes back to you.

Regulations

Fresh or processed vegetables come under different regulations, depending on where they are marketed and the level of processing. There are regulations relating to grading, packaging and labelling as well as health regulations, which cover how products are prepared and handled.

Fresh vegetables, which may be sold outside the province in which they are grown, come under federal grade and packaging standards, which are contained in the Fresh Fruit and Vegetable Regulations (under the *Canada Agricultural Products Act*). Provincial standards may also be in place, depending on the province. Check with your provincial specialists to determine which regulations apply to the products you plan to sell.

Processed products come under the *Processed Products Act* and associated regulations. These regulations govern how products may or may not be prepared and how processed products (whether frozen, canned, etc.) are labelled. Complying with these regulations may involve significant costs. Failure to comply would expose you to legal liability if a customer initiated a legal action against your business.

Labelling standards are in place for fresh and processed products. These standards specify what types of information must be included on a labelled product. Information that must be on a label includes farm name and contact information, type of product, weight or unit of measure. Additional information may be required, including grade, country of origin, nutritional information, etc. Consult applicable regulations for current requirements.

VEGETABLE PRODUCTION RECOMMENDATIONS

Vegetable Production Recommendations

Introduction

This chapter gives recommendations for specific vegetable crops and outlines the accepted production practices for each crop. It is not possible to cover all contingencies that may occur with every crop or every detail that might be of value for each vegetable crop. Recommendations are based on past research or on accepted practices in the Canadian Prairies.

The general fertilizer recommendations listed are to be used as a GUIDE ONLY. Growers are urged to soil test yearly and base fertilizer applications on the results of these tests. The small fee charged for a soil test can more than pay for itself through increased yields where baseline soil fertility is low or through fertilizer savings where soil fertility is high. Fertilizer recommendations are based on research or on a consensus of recommendations from other production areas.

For each crop, the main disease and insect pests are outlined as well as their general management practices. Registered chemical controls for weeds, insects and diseases are not listed due to the rapid addition of new products and changes to label recommendations. Contact your provincial specialists or consult other information resources for currently registered products and label recommendations. Consult pesticide labels for specific application details and follow label rates, application guidelines and other details. **It is illegal to use a chemical product on a crop if the product is not registered for that crop or for the specific use.**

Thousands of varieties (cultivars) exist for each vegetable crop. Consult other vegetable producers, seed company representatives or other sources for information on currently available and recommended varieties. Whenever possible, test varieties in your own fields to determine which ones perform best for you.

Grade and packaging standards are regulated by the federal and/or provincial government and are mainly applicable to vegetables being marketed through wholesalers. Not all vegetable crops are governed by grade regulations. Where no legal grade regulations exist, sell only top quality produce that is fresh and free from blemishes, diseases and insects. In many cases, buyers will set the required standard for the produce.

Some special terms appear in this chapter, so the Glossary in the Appendix will provide definitions and clarity for readers less familiar with the terminology.

Root vegetables

Beets

Varieties/cultivars

Beet cultivars are available in various root shapes, ranging from the more typical round shape to cylindrical. Beets also come in a range of colours, with a deep red being the most typical.

Climate and soil requirements

Beets grow best at air temperatures between 15 and 18°C (60 and 65°F) and can tolerate up to 24°C (75°F). Beets do best on well drained soils of different textures. Avoid soils that crust. Beets are also somewhat salt-tolerant compared to other vegetables.

Planting

Seed when the soil temperature is over 4°C (39°F). The optimum range for germination is 10 to 24°C (50 to 75°F). Sow bunch beets at bi-weekly intervals.

Plant 1 to 2 cm (0.5 to 0.75 in.) deep. Space rows 30 to 40 cm (12 to 16 in.) apart, and set the seeder to give a final in-row spacing of 5 to 8 cm (2 to 3 in.). Double line seed rows should be planted if a belt seeder is used. Between-row spacing must be adequate to allow for mechanical harvesting.

Beets may also be seeded in the fall for an earlier crop the following year; however, this is not a common practice. See the discussion on Fall Seeding in Establishing a Desired Plant Stand section in the Field Production chapter for more information.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. In general, apply the following:

- 39 to 72 kg of N/ha (nitrogen) (35 to 65 lb. N/ac.)
- 121 to 160 kg of P/ha (phosphorus) (110 to 145 lb. P/ac.)
- 127 to 165 kg of N/ha (potassium) (115 to 150 lb. K/ac.)
- 28 kg of S/ha (sulphur) (25 lb. S/ac.)

Fertilizer can be broadcast and incorporated before seeding. If banding phosphorus or potassium, reduce the rate to one-fifth and one-half, respectively. If necessary, 24 to 36 kg N/ha (22 to 33 lb. N/ac.) can be side-dressed during the growing season.

In some areas, on alkaline soils after prolonged hot, dry conditions, apply 11 to 22 kg/ha (10 to 20 lb./ac.) of borax with other fertilizers or apply 1.1 to 4.4 kg/ha (1 to 4 lb./ac.) as a foliar application. This procedure may help prevent internal black spots.

Irrigation

Beets have similar moisture requirements to carrots. Mature plants are moderately deep rooted, which will allow them to draw moisture from a reasonable depth in the soil profile. However, for a large portion of the growing season, beets draw moisture from within the shallow rooting profile.

In general, beets will require about 25 mm (1 in.) of water every 2 weeks (including precipitation). Ensure that moisture is sufficient during germination and seedling emergence as well as when roots are filling.

Insect pest management

Beet leafminer (*Pegomya betae*)

Beet leafminer; Left, leaf mine. Right, maggot
Photo: Courtesy F. B. Peairs; Reproduced, by permission, from Harveson, R. M., Hanson, L. E. and Hein, G. L. 2009. Compendium of Beet Diseases and Pests, 2nd ed. American Phytopathological Society,St. Paul, Minn.

Description/life cycle

Vegetable crops attacked by the beet leafminer include beets, spinach, sugar beets and Swiss chard. Eggs are laid in clusters of varying sizes on the lower surface of the leaves. The cylindrical and whitish/yellowish larvae feed within the leaf surface (mining). The larvae may occur singly or in aggregations. Pupation occurs in the soil directly beneath the affected plants. Adults are small, hairy, greyish to brown flies. The life cycle takes 30 to 40 days to complete.

Damage/symptoms
Larvae feeding within the leaves (between upper and lower leaf surfaces) form a mine that begins in a linear fashion but becomes a blotch with increased feeding. Damage is of economic importance only when the leaves are being sold for consumption, as the mines do not reduce yields of beet roots.

Control/management
In smaller production schemes, row covers can be extremely effective as they deny the leafminer access to the crop. Larger acreages require management with soil drench applications of insecticides. Early or late beet plantings may be outside the pest's peak flight periods, avoiding the need for control measures.

Beet webworm (*Loxostege sticticalis*)

Beet webworm larva
Photo: Courtesy F. B. Peairs; Reproduced, by permission, from Harveson,R. M., Hanson, L. E. and Hein, G. L. 2009. Compendium of Beet Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/life cycle
Vegetable crops attacked by the beet webworm include beet, cabbage, cantaloupe, carrot, cucumber, garlic, lettuce, mustard, onion, pea, potato, pumpkin, rhubarb, spinach and turnip.

Adult moths are greyish brown with irregular dark and light markings on the forewings. Moths appear in June, and all stages may be present at any time until fall. Eggs are deposited singly or in clusters, typically on the underside of the leaves.

Larvae are green, yellow or occasionally darker with a broken dark stripe on each side. Numerous white circular spots mark each body segment.

Larval size ranges from 4 to 20 mm (0.15 to 0.79 in.) as they progress through five instars (developmental stages). The larvae take between 17 and 20 days to reach maturity, depending on temperature. Generation time is typically 30 to 40 days, with 3 to 4 generations per year.

Damage/symptoms
Larvae feed on the underside of leaves, leading to skeletonization. Larger larvae feed on remaining leaf tissues, causing holes and ultimately consuming everything except the larger veins and stems. Large larvae may disperse in aggregations over long distances if densities of the pest are sufficiently high.

Control/management
Although primarily a pest on sugar beet, the beet webworm will also feed on table beet and Swiss chard. Numbers of this pest in Alberta and Manitoba have declined somewhat with the reduction in sugar beet production in these areas. Little in the way of control is necessary as this pest has become uncommon.

Disease management

Cercospora leaf spot (*Cercospora beticola*)

Cercospora leaf spot lesions with characteristic red-purple border
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
Crop losses are due to a reduction in beet root size and weight. The pathogen overwinters in diseased leaves as sclerotia (hardened structures that allow survival through harsh conditions), with the potential to survive for two seasons. Infected seed and weed hosts can introduce the pathogen to previously clean fields. The pathogen's penetration of the leaf occurs via the leaf stomates (minute openings).

Night temperatures above 16°C (61°F) and relative humidity above 90 per cent can favour a disease outbreak. Temperatures between 25 and 35°C (77 and 95°F) are optimal. The disease can spread and develop rapidly through rain splash, overhead irrigation, insect pests and the movement of equipment and personnel.

Damage/symptoms
Initial symptoms involve the appearance of small (2 mm; 0.08 in.) white, tan to brown spots with a distinct red-purple border on the leaves. Petioles (leaf blade stems), flower bracts, seed pods and seeds can all show symptoms.

Over time, the spots expand in size, becoming grey and brittle so that the tissue falls out, leaving a ragged hole. Numerous lesions may coalesce, followed by chlorosis (yellowing) and death of the oldest leaves, which remain attached to the plant.

Control/management
Use resistant cultivars, if available. Destroy volunteer host plants and deep plough crop residues to remove inoculum sources and overwintering sites. Maintain a minimum rotation of 2 years (preferably 3 years) with non-susceptible crops (such as cereal crops). A limited number of protective fungicides are available.

Phoma leaf spot, root rot, blackleg (*Pleospora bjoerlingii = Phoma betae*)

Phoma leaf spot of table beet
Photo: Courtesy L. J. du Toit; Reproduced, by permission, from Harveson, R. M., Hanson, L. E. and Hein, G. L. 2009. Compendium of Beet Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Comparison of common foliar diseases (left to right): Cercospora leaf spot, Alternaria leaf spot, Phoma leaf spot and bacterial leaf spot
Photo: Courtesy R. M. Harveson; Reproduced, by permission, from Harveson, R. M., Hanson, L. E. and Hein, G. L. 2009. Compendium of Beet Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Worldwide, diseases caused by this pathogen are the most destructive disease problems in beets and are generally found at low levels in most regions where beets are grown in Canada.

This pathogen is capable of causing symptoms on all plant parts. Problems can occur throughout the growing season, as well as in storage. This fungus is soil-borne and is spread by rain splash and sprinkler irrigation. The development of this disease is favoured at temperatures below 15°C (59°F).

Damage/symptoms

On young plants, the pathogen causes a pre-emergent damping-off similar to that caused by the pathogen *Pythium*. This phase of the disease can cause extensive crop loss. Seedlings that do emerge may have brown hypocotyls and/or black lesions on stem tissues in contact with the soil.

Damage to the root begins as small, soft, water-soaked lesions that turn into sunken brown to black lesions. A distinct line clearly delineates healthy and diseased tissue. Older diseased tissues may appear black and dry, and may have a spongy texture, with cavities within the root. These symptoms may appear similar to boron deficiency.

Leaf spots may be up to 2 cm (0.78 in.) across. They are brown and round to oval, with concentric rings containing pycnidia (fungal fruiting structures). Leaf spots are more typically found on older leaves and are typically less damaging than the root damage phase.

Control/management

Using clean seed is the best option for reducing occurrence of the disease. Maintain a 4-year crop rotation, as this fungus will survive in soil. Lamb's quarters is also a host of *Phoma betae* and should be controlled, especially in the rotational crops in non-beet years.

Plant seeds into warm soil and maintain adequate levels of phosphorus, potassium, manganese and boron to encourage vigorous growth and development.

The use of a fungicidal seed treatment or a hot water treatment will help reduce seed rots. Hot water treatment can be difficult on a commercial scale.

If the beets are to be stored, avoid close topping and wounds near harvest time. Encourage the development of callus tissue by storing at 10°C (50°F) for 2 weeks at 95 per cent relative humidity with sufficient air movement.

Weed management

Beets require the careful management of weeds for the first 4 to 6 weeks of growth. However once established, the beet crop is quite tolerant of weed competition. Weeds should be managed before planting. A limited range of herbicides is registered for use in beets. Careful selection of chemicals is a must. Some residual products will affect subsequent beet plantings.

Harvesting

The anticipated end use of the crop will determine the optimum time for harvest.

Beets can be grown for their tops (greens). Beet greens should be harvested when they are tender.

Typically, bunch beets (with tops) are harvested at a younger stage than beet roots intended for longer-term storage. Bunch beets are often harvested before they reach full maturity.

Beets intended for storage should be harvested when the roots are mature, which is generally when the beets have reached the desired size. Harvest when the weather is cool.

Post-harvest handling and storage

Storage beets should be topped and graded for defects and size before storing. Smaller beets and cylindrical cultivars tend to have a more limited storage lifespan than large, round beets. Maintain a storage temperature of 4 to 5°C (39 to 41°F) and a relative humidity of about 95 per cent. Beets will store up to 4 or 5 months under these conditions.

Bunch beets are not held for long periods in storage, although they can be held for 10 to 14 days at 0°C (32°F) and high relative humidity. Generally, bunch beets should be harvested as close to the time of sale as possible.

Harvested beet greens will not have a significant post-harvest lifespan.

Beets are generally not washed prior to storage, but should have excess dirt removed to improve airflow around them. Washing should occur before the beets are sold.

Carrots

Varieties/cultivars

Carrot cultivars are commonly classified by their root shape (see Figure 7):

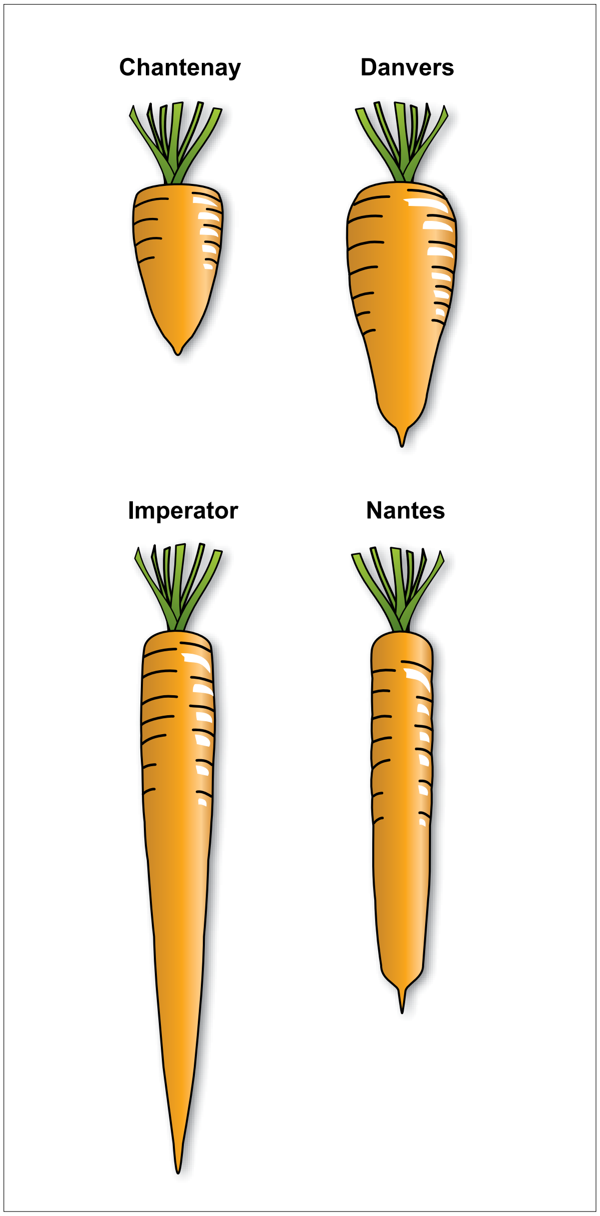


Figure 7. Carrot root shapes

Chantenay carrots are shorter and wider than other cultivars. They have broad shoulders and taper toward a blunt, rounded tip. Chantenay carrots are commonly diced for use in canned or prepared foods.

Danvers carrots have a conical shape and taper to a point. The roots are longer than Chantenay types but shorter than Imperator cultivars. The tops are vigorous, which makes them well suited to mechanical harvest. Danvers cultivars are high yielding, but the quality declines as the roots mature. Danvers carrots are popular in frozen or processed foods.

Imperator carrots are long and taper to a point. The tops are vigorous, and yields are high. Imperator carrots are common in supermarkets.

Nantes carrots are cylindrical and the ends are blunt and rounded. The tops are small and the roots brittle, making them difficult to harvest mechanically. Nantes cultivars are often sweeter than other types of carrot.

Hybrids combining differing carrot shapes and quality characteristics are available (e.g. Nantes x Imperator).

Climate and soil requirements

Carrots grow best at temperatures between 15 and 18°C (60 and 65°F) and can tolerate up to 24°C (75°F). Excessively high temperatures at certain growth stages can result in poor stands, poor flavour and various physiological disorders.

Carrots should be grown on a well drained soil. They do best on loose, friable, sandy loam soils. Soils with too high a sand content may result in scratching during mechanical harvest. It is possible to grow carrots on heavier soil if the proper cultural practices are followed.

Prepare a uniform, well worked seedbed before seeding. Because of the rooting habits of this crop and the desirability of producing a high percentage of long, straight, smooth roots, work the soil to a minimum depth of 30 cm (12 in.). This preparation allows for unobstructed root extension and development, easy moisture penetration and adequate aeration of the soil.

To create a deeper seedbed, the soil can be shaped into raised beds, using a range of implements, before planting.

Planting

Carrots should not be planted into cold soil as they do not germinate well below 10°C (50°F). On the Prairies, carrots are typically seeded between May 1 and 15, although seeding may be earlier or later in some areas. If seeding is delayed, seeding rates may have to be reduced to allow roots to develop to marketable size before severe frosts kill the tops.

Carrots are shallow-seeded 1 to 2.5 cm (0.5 to 1 in.). Germination can be hindered or the crop may be killed if the soil around the germinating seeds dries out. Irrigation is often essential for establishing a good stand of carrots (see the Irrigation text later in this Carrots section).

Depending on seed size and the stand required, a grower may use from 1 to 7.3 kg/ha (0.9 to 6.6 lb./ac.) of seed. Normal seeding requirements range from 2.24 to 5 kg/ha (2 to 4.5 lb./ac.). Processing types may have seeding rates ranging from 1 to 2 kg/ha (0.9 to 1.8 lb./ac.).

Long-type carrots grown for storage should be planted to achieve a final stand of about 100 plants/m (30 plants/ft.) in a triple-line band 7 cm (3 in.) wide. The centre line of the seed belt should have about 30 to 50 per cent fewer holes than the outside lines. Long type carrots or Nantes types grown for early bunching or early cello pack trade should be planted to achieve a final stand of 60 to 100 plants/m (20 to 30 plants/ft.).

Carrots are difficult to germinate on coarse-textured mineral soils. Field conditions (field factor) and per cent germination can also greatly reduce the percentage of the seeds planted that actually emerge. A normal range for emergence is 40 to 60 per cent, which means that for every 100 seeds planted, about 40 to 60 carrot plants will become established. As a rule of thumb, use 50 per cent emergence as a planting guide.

Row spacing must be compatible with your tillage, spraying and harvesting equipment. Although mechanical harvesters can be adapted to harvest rows as close as 30 cm (12 in.) apart, growers find it difficult to harvest most varieties if the rows are less than 45 cm (18 in.) apart because the tops tend to bind together between the rows. This problem is increased if heavy frost weakens and drops the tops.

Normally, cello pack carrots are grown on single-row beds spaced 60 cm (24 in.) on centre (i.e. from the centre of one row or bed to the centre of the next row or bed). Alternative planting arrangements include 3 or 4 rows on beds with 1.8-m (6-ft.) centres or 2 rows on beds with 90-cm (3-ft.) centres. Single-row beds spaced 60 cm (24 in.) on centre have 50 cm (20 in.) wide tops and are 15 to 20 cm (6 to 8 in.) high.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally, broadcast and incorporate the following before planting:

- 80 to 110 kg N/ha (70 to 98 lb. N/ac.)
- 121 to 133 kg P/ha (110 to 121 lb. P/ac.)
- 250 kg K/ha (223 lb. K/ac.)

A portion of the required nitrogen (36 kg/ha; 33 lb./ac.) can be applied during the growing season through the irrigation system or by broadcasting over the crop. If banding the phosphorus, reduce the rates to one-fifth.

Over-application of nitrogen can result in excessive top growth, which makes the crop prone to many diseases. Be sure to base nitrogen applications on soil testing.

Irrigation

Carrots do not tolerate drought. Irrigation is essential for establishing a good stand of carrots, for promoting the development of long, straight roots and for the overall health and yield of the crop. Seeding may have to be delayed until irrigation water is available. Irrigation can overcome soil crusting or dry conditions at seedling emergence.

Carrots may use 4 to 6 mm (0.16 to 0.24 in.) of water per day during peak-use periods (up to 35 mm or 1.3 in. per week). Critical moisture periods are during general growth and during the time when roots are filling.

Insect pest management

Aster leafhopper (*Macrosteles quadrilineatus = Macrosteles fascifrons*)

Aster leafhopper adult
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
Some of the crops attacked by the aster leafhopper include carrot, celeriac, celery, corn, echinacea, lettuce, parsley, potato and radish. This pest also feeds readily on canola and a number of other field crops.

The aster leafhopper overwinters primarily in the Gulf States of the southern United States, migrating to Canada in May or June. This leafhopper may overwinter in the egg stage in northern regions depending on winter temperatures and amount of snow cover. In Manitoba, there are three generations per year.

Eggs are typically laid in the leaf, petiole or stem tissue of non-vegetable hosts because vegetables are not suitable for nymphal development. Suitable hosts include various grasses, cereals and clovers. Nymphs resemble wingless adults. Adults are typically small, 3.2 to 3.8 mm (0.13 to 0.15 in.) in length and light green to greyish green. There are six markings (dots or dashes) on the head that give rise to the common name six-spotted leafhopper.

Damage/symptoms
Leafhoppers feed by piercing the leaf tissue of plants and sucking out the sap. Feeding causes minor damage to plants, but major damage is caused by the transmission of aster yellows phytoplasma, the pathogen that causes aster yellows disease.

Phytoplasma-infected plants show various symptoms of infection including stunting, hairy roots, discolouration (often purple foliage) and deformed roots or aerial structures. Infection also causes carrots to take on a bitter taste. Between 2 and 5 per cent of leafhoppers carry the phytoplasma.

Hairy root caused by aster yellows in carrot
Photo: Manitoba Agriculture, Food and Rural Development

Monitoring
Aster leafhopper populations may be monitored using sticky traps or sweep nets. Monitoring should start at the end of May and can continue for as long as the crop is in the field, although control treatments would not typically be applied after a certain point.

Economic damage thresholds for leafhoppers have been established for a number of crops based on the Aster Yellows Index (Table 29). The index is calculated as follows:

Aster Yellows Index (AYI) = per cent infectivity in leafhopper population x number of leafhoppers per 100 sweeps

The level of infectivity in the leafhopper population is determined annually through testing by labs in Wisconsin.

Table 29. Aster Yellows Index (AYI) values for economic damage thresholds for some vegetables

Crop	AYI
Carrots – general	about 50
Carrots – resistant cultivars (e.g. Six Pak II)	100
Carrots – intermediate cultivars	70 - 75
Carrots – susceptible cultivars (e.g. Spartan Bonus)	40 - 45
Celery, romaine lettuce	30 - 35
Head lettuce	20 - 25

AYI values vary by cultivar, but in general, a value of 50 can be used for most carrots. If the AYI value is higher than the threshold, take action to control leafhoppers.

Control/management

Using less susceptible varieties can reduce the effect of aster leafhoppers and aster yellows. Controlling weeds in the crop and in adjacent rough areas (headlands and ditches) can influence the relative number of host plants available for the leafhoppers to live on. It has been suggested that irrigation can attract leafhoppers, as it makes plants more succulent.

The phytoplasma cannot be managed, so the leafhoppers themselves must be controlled with insecticides. By linking pesticide applications with peak leafhopper numbers (derived by regular monitoring), producers can reduce populations using a reduced number of spray applications.

Carrot rust fly (*Psila rosae*)

Carrot rust fly larvae
Photo: British Columbia Ministry of Agriculture

Tunneling of carrot root caused by carrot rust fly
Photo: British Columbia Ministry of Agriculture

Description/life cycle

The carrot rust fly attacks all crops in the carrot family (Umbelliferae). While not a major pest in the Prairie region, the carrot rust fly can cause significant damage when found in abundant numbers. It overwinters as a pupa in the soil, emerging as an adult in June.

Adults are slender, shiny black flies, about 6 mm (0.24 in.) long. Adults have distinctive red heads and long yellow legs. Eggs are deposited on the ground. The maggot larvae tunnel into the root, typically feeding on the lower third of the root (carrot weevils typically feed on the upper portion of the root). Two generations per year are possible in the Prairies.

Damage/symptoms
Damage is caused by larval tunnelling in the root, rendering the carrot unmarketable. Roots may be forked, stunted or fibrous depending on the timing of damage.

Control/management
Use yellow sticky traps to monitor adult fly populations. Biological control agents are not well known. Management is primarily through the use of foliar insecticides that target the adult flies.

Carrot weevil (*Listronotus oregonensis*)

Carrot weevil adult
Photo: Manitoba Agriculture, Food and Rural Development

Larval stage of carrot weevil
Photo: Manitoba Agriculture, Food and Rural Development

Damage from carrot weevil larvae
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
Known only from Manitoba in the Prairies, the carrot weevil is a pest of minor importance. Carrot weevils overwinter as adults around carrot fields and move into the fields in spring to feed on the foliage. In Manitoba, trapping of adults yields the highest numbers in early June.

Adults are 6 mm (0.24 in.) long, dark brown beetles with a snout. Eggs are generally laid on petioles when plants reach the four-leaf stage. The larva is a legless grub with a reddish brown head.

Larvae tunnel into the main root, usually feeding in the upper portion of the root (the carrot rust fly feeds in the lower third of the root), rendering the root unmarketable.

Typically, only a single generation is produced per year, although adults will remain in reproductive diapause (suspended development) through the latter half of the growing season.

Damage/symptoms
Larvae tunnel into the petiole, heart, crown or centre and roots of the plant. Visible root scarring may render the carrots unmarketable, and young carrots may wilt or die from attack. In heavily affected areas, damage may reach upwards of 70 per cent yield loss.

Control/management
Crop rotation is effective in non-intensive carrot production areas. Naturally occurring bio-control agents are common in most fields. Biological controls have not been commercially developed. Chemical control is effective based on scouting using baited traps.

Disease management

Alternaria leaf blight (*Alternaria dauci*)

Description/disease cycle
Alternaria leaf blight is the most common leaf blight observed in carrot crops and can cause significant yield losses, primarily through a reduction in photosynthetic area, as well as by making removal of the carrot from the ground very difficult. Early infections can result in damping-off of the young seedlings.

Damage/symptoms
Initially, olive-brown foliar lesions often occur on or near the edge of leaflets. Over time, the lesions become black with a yellow border. Severe spotting creates a brown, blighted appearance. As lesions coalesce over larger portions of the leaf surface, the leaves will die. Lesions on petioles may girdle the petiole, leading to collapse and death of the entire leaf. At the field level, large patches of blighted foliage may be visible in severe outbreaks.

Leaf lesions of alternaria leaf blight on parsnip
Photo: Manitoba Agriculture, Food and Rural Development

Compared to cercospora leaf blight, symptoms tend to appear later in the season because older leaves are more susceptible than younger leaves. As symptoms of both alternaria and cercospora leaf blight can appear quite similar, laboratory analysis may be necessary to confirm the causal agent.

Control/management
Use pathogen-free seed to prevent the introduction of the pathogen into a field. If there is a low level of seed-borne infection, treat carrot seed with hot water. Maintaining a 2- to 3-year rotation to non-host crops and ploughing under crop residue at the end of the growing season can reduce carry-over of the fungus.

Cultivars vary in their tolerance to alternaria leaf blight. In areas where this disease problem occurs frequently, consider using tolerant cultivars. Tolerant cultivars include, but are not necessarily limited to the following:

Apache	Enterprize	Sherbert
Bolero	Inca	Sirkana
Big Sur	Indigo Winter	Magnum
Black Knight	Interceptor	Sun 255
Cellobunch	Kuroda	SunLite
Choctaw	Laguna	Sweet Bites
Cordoba	Maverick	TenderSnax
Crème de lite	Nectar	Topcut 93
Cumbre	Nevada	Triple Play 58
Dillion	Primecut 59	Upper Cut 25
Eagle	S-505	Sugarsnax 54

Consult your local seed supplier for updates to the list of tolerant cultivars.

Aster yellows (aster yellows phytoplasma)

Damage in field from aster yellows phytoplasma
Photo: Manitoba Agriculture, Food and Rural Development

Hairy root and witches' broom indicative of aster yellows infection
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
Aster yellows is caused by a micro-organism known as a phytoplasma that is capable of causing disease in over 300 plant species. The aster yellows (AY) phytoplasma is present across

Canada. On the Prairies, a wide range of crops and weed species can become infected by aster yellows.

Vegetable crops (broccoli, cabbage, carrot, cauliflower, celery, cucurbits, garlic, lettuce, onion, parsnip, potato, rutabaga and tomato) typically suffer the greatest damage relative to other crops, due to the reduction in marketable quality and appearance, and to the unpalatable taste caused by the infection.

The aster leafhopper is considered the chief vector of the aster yellows phytoplasma (see Aster Leafhopper in the Insect Pest Management portion of the Carrots section).

Damage/symptoms
See Aster Leafhopper in the Carrots section (as above) for a description.

Control/management
As there is no practical way of controlling the phytoplasma directly, the leafhopper vector must be managed in high value crops, such as carrots, lettuce and many other vegetables (see Aster Leafhopper in the Carrots section, as above). Leafhoppers should also be controlled in perimeter areas.

Carrot plantings should be isolated from forage legume fields and rough weedy areas where leafhoppers may abound. Remove infected plants as soon as detected, if practical. Seeding earlier may provide some benefit if leafhoppers arrive late in crop development. Cultivars vary in their tolerance, but none are known to be resistant.

Cercospora leaf blight (*Cercospora carotae*)

Early leaf lesions of cercospora leaf blight
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
Cercospora leaf blight can cause considerable losses to carrot crops. In seasons and regions where humidity levels are high and leaves remain wet for prolonged periods, management of this disease can be very difficult. Damage to leaves can create problems with mechanical harvesting, as the leafy tops will break away from the taproot.

Occasionally referred to as early blight of carrot, cercospora leaf blight tends to appear earlier in the season than alternaria leaf blight.

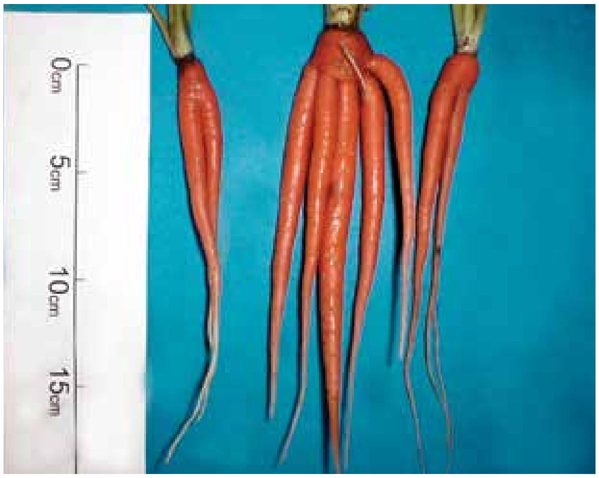
Damage/symptoms
Initially, small (1 to 3 mm; 0.03 to 0.11 in.), necrotic, grey-brown, angular leaf flecks appear. These lesions enlarge to grey-tan spots with yellow borders (halos). As the lesions cover more leaf area and combine into larger blighted areas, entire leaves can dry up and die. Petiole lesions appear as brown, oval spots with a pale centre.

Severe infections can make machine harvesting difficult as the weakened leaves tear away from the taproot. The roots themselves are not susceptible to infection by the fungus.

Control/management
This disease can be seed-borne, so always use clean seed. Plough all crop refuse under after harvest. Also use 2- to 3-year rotations away from carrots. Apply protective fungicides when the disease is detected to further reduce damage and spread of the disease.

Some cultivars have a degree of tolerance to cercospora leaf blight. These cultivars include the Nantes types Bolero and Nectar and the Imperator types Choctaw, Primecut 59, Sugarsnax 54, Topcut 93 and Triple Play 58. Consult your local seed supplier for additional tolerant cultivars.

Forked carrots (physiological disorder)



Forked carrots due to damaged meristem
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
Carrot forking occurs when the root apical meristem (growing point) is damaged, resulting in the regrowth of two or more root tips. This problem has been attributed to a number of possible causes including soil compaction, nematode damage, *Pythium* damage and herbicide damage.

Damage/symptoms
Forking reduces root length and quality. The earlier the damage occurs, the greater the degree of forking. Carrots may also break during harvest due to the distorted shape.

Control/management
As this problem has a number of possible causes, determining the specific cause of the forking is often necessary. This analysis can be difficult.

Encourage conditions that promote long, straight carrots. If possible, grow carrots in light-textured soils or muck soils with adequate drainage. Another option is to use raised beds for growth in well worked soil with improved drainage and aeration.

If a soil-borne pathogen such as *Pythium* is present, fungicide options in conjunction with rotations to other crops may reduce the number of forked carrots in a field.

Sclerotinia rot, white mould, cottony rot, watery soft rot (*Sclerotinia sclerotiorum*)

Sclerotinia mould on carrots in storage
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
White mould is primarily a destructive storage rot on carrots and parsnips, but symptoms can also develop in the field. This pathogen can cause disease on a number of other horticultural and field crops, including pulses (e.g. peas, beans), many oilseeds and weed hosts. Therefore, this disease is a concern virtually every year. The wide host range of this fungus also makes management very difficult.

Leaf and stem tissue infection occurs through mycelium (fungal filaments) arising from soil-borne sclerotia (hardened black structures that allow survival through harsh conditions). Infection of the leaves can lead to infection of the root.

Damage/symptoms
Initially, the symptoms appear as 1-cm (0.4-in.) wide, brown spots on leaf or crown tissues or on the exposed shoulders of taproots. Diseased leaves are dark brown and become covered with the white cottony mycelium. After the death of the plant tissue, the white mycelium produces sclerotia.

Foliar infections can reduce yields by weakening the leaves or causing a root rot in the field, which leads to the production of sclerotia on the taproots.

In storage, the fungus can proliferate through the rapid growth of mycelium, which can spread from diseased to healthy carrots, resulting in significant losses.

Control/management
Growing carrots on raised beds or ridges may reduce the incidence of foliar infection. Clipping or cutting the lower, outer carrot foliage promotes air circulation and reduces infection.

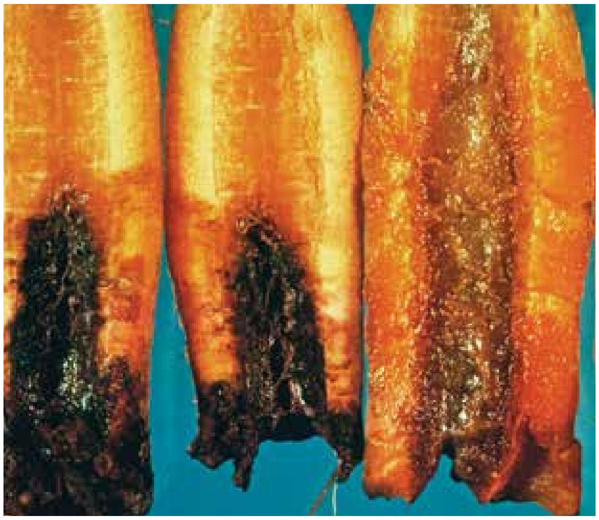
Rotate with resistant crops such as grasses, cereals, beets, onions, spinach or corn. Plant crops in well drained soil. Use a plant spacing that will allow good air circulation between plants. Practise good field sanitation by removing and destroying diseased plants.

Applying registered fungicides or bio-fungicides in the field can reduce infection before harvest and reduce the degree of disease introduced into storage.

Handle carrots and parsnips carefully throughout all stages of harvesting and washing. Quick cooling of harvested carrots to 0°C (32°F) helps minimize disease outbreaks in storage. Inspect the storages frequently and attempt to remove any diseased carrots or containers where the disease is developing.

Disinfect storage bins before harvest. Clean and disinfect storage containers between batches of carrots. The use of registered fungicides before storage (as a spray or dip; see specific product label for details) may reduce disease outbreaks in storage.

Soft rot (various *Erwinia* species)



Soft rot damage
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Characteristics of soft rot in carrots are similar to those exhibited in other crops. See Bacterial Soft Rot in the Potatoes section further on in this chapter for details.

Damage/symptoms
Symptoms include a smelly, watery soft rot of tissues, similar to that observed in other crops. See Bacterial Soft Rot in the Potatoes section for detailed information.

Control/management
Harvest and handle the crop carefully to avoid bruising. Cull rotted roots before storage. Allow roots to dry before storing. Store under cool (0 to 1°C; 32 to 34°F) and humid (90 to 95 per cent relative humidity) conditions with adequate aeration. Disinfect storages between crops.

Weed management

Weed control is critical throughout the crop's entire growing cycle as carrots are small, slow-growing plants that are poor competitors. A number of chemical herbicides are registered for use in carrots that offer excellent control of most annual weeds. Control perennial weeds before planting.

Harvesting

Generally, carrots are harvested when they have reached an appropriate size for their specific end use. Early carrots are harvested when they are still tender and sweet. For long-term storage, a physiologically mature carrot is desired, with maximum sugar and high monosaccharide content.

Post-harvest handling and storage

Quick removal of field heat will lengthen the storage period and reduce problems with disease during storage. Before storage, remove carrot tops, clean and wash carrots and discard damaged or diseased roots.

Suitable cultivars of mature topped carrots store well for up to 5 to 9 months when held at 0°C (32°F) and more than 95 per cent relative humidity. Ensure that stored carrots are free from disease or damage to reduce the incidence of storage rot.

Even with perfect storage conditions, some degree of loss (weight, quality, etc.) can be expected. Some post-storage grading should take place to remove unmarketable product.

Parsnips

Varieties/cultivars

A limited amount of information is available on new varieties or cultivars. Consult seed companies about available varieties that might be suitable for your area.

Climate and soil requirements

Parsnips are a cool-season crop, preferring temperatures between 15 and 18°C (60 and 65°F) and not exceeding 24°C (75°F). Excessively high temperatures can result in poor stands or in the formation of distorted, coarse and bitter roots. Parsnips are frost tolerant.

The soil types and soil preparation steps for parsnip are identical to those for carrot (see Climate and Soil Requirements in the Carrots section).

Planting

Parsnips are a very long-season crop and tend to be very slow to germinate, particularly in cool, dry soils. Therefore, it is essential to sow early to obtain good yields of high quality parsnips. Parsnips can germinate at temperatures as low as 2°C (35°F), with an optimum range from 10 to 21°C (50 to 70°F), which can allow early season germination.

Seed at a rate of about 3 to 5.4 kg/ha (2.7 to 4.9 lb./ac.). Place the seed 1 to 2 cm (0.5 to 0.75 in.) deep. Seeds can be planted in a double line band 7 cm (3 in.) wide. Final stands should have 20 to 30 plants/m (6 to 10 plants/ft.). Rows are spaced 45 to 75 cm (18 to 30 in.) apart.

Ensure that soils do not become dry or crusted before seedling emergence as these conditions will reduce the final stand.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally broadcast and incorporate the following:

- 110 to 121 kg N/ha (100 to 110 lb. N/ac.)
- 121 to 132 kg P/ha (110 to 120 lb. P/ac.)
- 83 to 110 kg K/ha (75 to 100 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If banding fertilizers, reduce the rates of phosphorus and potassium to one-fifth and one-half, respectively. During the growing season, an additional 36 kg N/ha (33 lb. N/ac.) can be applied as a broadcast application or via the irrigation system, if required.

Irrigation

Parsnips have similar moisture requirements to carrots. They are intolerant of dry or hot conditions; therefore, irrigation is typically a requirement to ensure a good quality crop.

Irrigation before and after seeding can help prevent soil crusting and prevent heat damage to emerging seedlings. During rapid elongation of the root, a steady supply of moisture is required. At maturity, irrigation should be slowed and reduced to promote the accumulation of sugars and to facilitate lifting during harvest.

Insect pest management

Insect pests that affect parsnips are similar to those that affect carrots (see Insect Pest Management in the Carrots section). Ensure that pest management practices are appropriate for parsnips before implementation.

Disease management

Diseases that affect parsnips are similar to those that affect carrots (see Disease Management in the Carrots section). Ensure that pest management practices are appropriate for parsnips before implementation.

Weed management

The weed management requirements for parsnips are similar to those of carrots; however, registered herbicides will not likely be the same. Consult pesticide labels for details. Control perennial weeds before planting.

Other requirements

Skin irritants

Parsnip foliage contains natural compounds that can cause skin rashes in sensitive individuals. Wear rubber gloves and leg protection when handling foliage or moving within the field.

Harvesting

Harvest parsnips when they have reached a suitable size. Parsnips can tolerate frost and are often sweeter following a frost, provided the root is not damaged.

Post-harvest handling and storage

The post-harvest handling procedures for parsnips are similar to procedures for carrots. Parsnips store best at 0°C (32°F) and at least 95 per cent relative humidity. Under the proper conditions, parsnips may be stored for 4 to 6 months.

Potatoes (table)

Varieties/cultivars

Potatoes are typically classified in terms of their end use and fall into three major potato categories:

- table (baking and boiling types)
- processing (chipping and french fry types)
- seed

Baking potatoes have a drier, mealy texture. The exterior is typically russetted (skin has a netted texture). Common cultivars include Russet Burbank, Russet Norkotah, etc.

Russet Burbank potatoes – for baking or frying
Photo: Robert Spencer

Boiling potatoes should be slightly wet, waxy and sweet, with minimal sloughing and after-cooking discolouration. Interior colour (white, creamy or yellow) and exterior colour (red, white or russetted) depend on market expectations. Common cultivars include Norland, Pontiac, Yukon Gold, Ptarmigan, etc.

Norland potatoes – for boiling
Photo: Robert Spencer

Chipping cultivars typically have round tubers with high specific gravity and low reducing sugar content. These characteristics result in a crisp, light-coloured chip. A common cultivar is Atlantic.

Atlantic potatoes – for chipping
Photo: Robert Spencer

French fry cultivars typically have long tubers with high specific gravity and low reducing sugar content. These characteristics result in a long, uniformly light-coloured fry with a mealy interior. Common cultivars include Russet Burbank, Ranger Russet, Shepody, etc.

Shepody potatoes – for frying
Photo: Robert Spencer

Climate and soil requirements

Potatoes can be grown in many different climatic areas. Growing conditions across the Prairies are especially well suited to potato production. Potatoes grow best in temperatures between 16 and 18°C (60 and 65°F) and not exceeding 24°C (75°F).

Potatoes are sensitive to spring and fall frost. Yields and some aspects of quality increase with duration and suitability of the growing season. In general, 60 frost-free days are required to get your seed back and 90 frost-free days to get a decent yield of early cultivars. Longer season cultivars require greater than 120 frost-free days to reach optimum yields and quality.

Tuber yield, shape, grade and ease of harvesting are influenced by the soil's texture and other physical characteristics. Medium-textured to light sandy loams and alluvial silt soils are desirable as they are easy to work and do not tend to stick to planting or harvesting equipment or to the tubers during wet digging periods. Heavier soils tend to be prone to waterlogging and can produce clods that bruise potatoes during harvest. Soils high in organic matter have good aeration, nutrient supply and water-holding characteristics.

Good drainage is essential in potato production. Poorly aerated, waterlogged soils restrict the air needed by the roots and promote soft rot. Soil pH should be between 6 and 7.5 for optimum growth. Soils should be stone-free.

Fields should have minimal slope. They should be accessible in all seasons and all weather (as much as possible). They should also be located reasonably close to storages to reduce transportation requirements.

Potatoes should not be grown year after year on the same land as this practice can damage soil quality and lead to a buildup of disease and insect problems. Rotate crops and include a legume (for nitrogen fixation) or a grass (for a break in weed and disease pressure) if possible. Rotations should be at least 3 to 5 years. If sod has preceded potatoes, wireworms may be problematic.

Soils that have previously produced potato crops with diseases such as scab or verticillium wilt should be avoided because these soil-borne diseases are persistent and difficult to manage.

Potatoes are very sensitive to herbicide residue. Therefore, a complete understanding of previously applied herbicides (both directly to the soil and indirectly through manure or compost) is required. If you are renting land, take particular care to determine if any residual herbicides have been applied that may be potentially damaging to the potato crop and/or have food safety consequences that could render the crop unmarketable.

Planting

Planting dates vary from early to late May, depending on local climatic conditions, the variety being grown and the anticipated market use. Potatoes should be planted as early as conditions permit, but soil temperatures should be at least 7°C (45°F). Avoid cold or wet soils at planting because cold, wet seed pieces will be slow to emerge and subject to rot, resulting in poor or uneven plant stands. Under good soil conditions, plants should emerge within 14 to 28 days after planting.

Potatoes are sensitive to damage from spring frosts. Plant growth can be slowed or stunted by near-freezing temperatures or directly injured by freezing. Some plant regrowth and recovery may occur, but it can be slow. Replanting may be required if damage is severe and extensive. Protecting plants from imminent frost with irrigation might be possible; however, covering the crop would not be cost-effective.

The equipment used for planting, cultivating, spraying and harvesting the potato crop will govern the required spacing between rows. Rows are usually about 90 cm (36 in.) apart. Wider spacing may be necessary when soil moisture and fertility are not adequate.

Seed spacing is critical in ensuring a uniform, high yielding, quality end product. Generally, as the in-row spacing of potatoes decreases (closer spacing), the field's yield potential increases, while the average tuber size in the resulting crop declines.

Market garden potato planter
Photo: Tom Gonsalves

Small-scale mechanized potato harvester
Photo: Tom Gonsalves

For table potatoes, seed pieces are typically spaced 20 to 30 cm (8 to 12 in.) apart in the row. Wider in-row spacings may be desirable when fertility is low and/or when moisture is lacking. For chipping and french fry potatoes, use wider spacings. Narrower in-row spacing is required for some varieties to prevent over-sizing, growth cracks or hollow heart.

Planting depths of 7 to 15 cm (3 to 6 in.) are commonly used. However, if it is necessary to plant into cold, wet, disease-prone soil, use shallower depths.

The amount of potato seed required depends on between-row and in-row spacings and the size of each seed piece. Table 30 indicates the amount of seed required to plant an acre at various spacings and with various seed sizes.

Table 30. Number of hundredweight of potato seed pieces required to plant one acre depending on size of seed pieces

Distance between rows		Space between seed pieces		Hundredweight of seed pieces required per acre		
(cm)	(in.)	(cm)	(in.)	40 g (1.5 oz.)	55 g (2 oz.)	70 g (2.5 oz.)
75	30	25	9	22	29	36
		30	12	17	22	27
		40	15	13	17	22
		45	18	11	14	18
90	36	25	9	18	24	31
		30	12	14	18	23
		40	15	11	14	18
		45	18	9	12	15
95	38	25	9	17	23	29
		30	12	13	17	21
		40	15	10	14	17
		45	18	9	11	14
105	42	25	9	16	21	26
		30	12	12	16	19
		40	15	10	12	16
		45	18	8	10	13

Using quality certified seed is critical to ensuring a high yielding, quality crop. Seed should be free of disease and other defects.

Seed can be either pieces of larger, cut tubers or whole tubers (also called drop seed). There are advantages and disadvantages with both options.

Cut seed should have a good number of eyes and should be treated to protect against disease. Cut seed is less expensive than whole seed and is readily available. Cutting seed increases the risk of disease transfer. In general, seed pieces should be from 45 to 85 g (1.5 to 3 oz.). Pieces that are too small can result in weak, unproductive plants. Pieces that are too large are more expensive to plant, without an increase in benefit over optimal pieces.

Whole seed is typically 62 to 124 g (2 to 4 oz.). Whole seed avoids many of the risks associated with cut seed pieces. However, whole seed is more expensive and may be challenging to find.

Seed size for either cut or whole seed should be as uniform as possible to ensure that machines do not have difficulty handling the seed during planting.

Handle seed carefully before planting to reduce seed stress. Maintain sanitary holding and handling conditions. Warm seed to 7 to 10°C (45 to 50°F) to encourage tuber dormancy to break and before any cutting to prevent bruising. After cutting, seed should be treated immediately, if required.

Seed should not be cut too far in advance of planting. If planting has to be delayed, seed can be held at 7 to 10°C (45 to 50°F) and 90 per cent relative humidity for 5 days in piles 1 to 2.4 m (3 to 8 ft.) deep provided there is good ventilation. Then, seed should be held at lower temperatures (3 to 8°C; 41 to 46°F) until planting. With the proper storage conditions, cut seed can be held for up to 3 weeks before planting, if necessary.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Fertilizer requirements for potatoes depend on soil type, availability of adequate moisture, variety, spacing and anticipated end use.

In situations where moisture is limited, potatoes will require a total (residual and applied) of the following:

- 138 kg N/ha (125 lb. N/ac.)
- 88 to 110 kg P/ha (80 to 100 lb. P/ac.)
- 440 kg K/ha (400 lb. P/ac.)
- 22 kg S/ha (20 lb. S/ac.)

Where rainfall is more abundant or irrigation is in place, increase fertilizer rates by 25 to 50 per cent.

Potassium may be required on some soils when soil tests show potassium levels to be less than 339 to 436 kg/ha (308 to 396 lb./ac.). Potassium is more likely to be required where potatoes, sugar beets and malting barley have been repeatedly grown. A small amount (22 kg/ha; 20 lb./ac.) of potassium is recommended at planting, regardless of soil residual quantities.

For short season cultivars or when yield potential and crop fertility needs are limited by a lack of irrigation, fertilizer rates may be reduced, and fertilizer response will probably be best when the majority of the P and K is applied early. Large amounts of N should not be applied with the seed or on land that is particularly prone to leaching.

In areas with a longer growing season and or in situations where the risk of leaching of applied nutrients is high (irrigation or coarse-textured soil), a split application of N may improve yields and/or increase fertilizer use efficiency. Apply 50 to 75 per cent of the fertilizer as a broadcast application before planting.

Apply the remainder either via banding at or around the time of tuber initiation or via fertigation throughout the growing season, as determined by tissue testing. The use of coated fertilizer products has the potential to allow more precise nutrient supply and reduce excess applications of nutrients.

Irrigation

Potatoes require up to 550 mm (22 in.) of water per season (including precipitation), depending on the soil type and weather conditions. Proper timing of the application of water is essential to maximize yield and quality. If the moisture requirement is not met by rainfall, the crop will respond strongly to irrigation, both in terms of yield and quality.

Irrigation can help reduce physiological defects and deformities that are associated with variable moisture.

Moisture in the soil profile should not be depleted beyond 65 to 70 per cent of field capacity. At peak use, potatoes will use up to 6 mm (0.24 in.) per day. Critical use periods are during tuber initiation and sizing. If your water supply is limited, save it for use during these critical periods.

Insect pest management

Aphids as virus vectors

Numerous species of aphids colonize potatoes, and these species all may vector (transmit) plant viruses at varying degrees of efficiency. On the Prairies, potato virus Y (PVY) and potato leaf roll virus (PLRV) are the two most important viruses vectored by aphids.

The primary aphids colonizing potatoes in the Prairies are buckthorn aphid (*Aphis nasturtii*), green peach aphid (*Myzus persicae*) and potato aphid (*Macrosiphum euphorbiae*). See Figure 6 in the Pest Management chapter. Other species may also feed in potatoes or simply probe the plants to determine if they are suitable hosts.

PLRV transmission typically requires aphids to colonize the crop, but PVY can be transmitted when an infected aphid simply probes a plant. Green peach aphid is considered to be the most efficient vector for the diseases affecting potato.

Description/life cycle
Aphid life cycles are tremendously variable. Aphids typically require two different host plants, one for overwintering and one for summer colonization. Overwintering is typically done on the winter host plant in the egg stage.

In spring, the eggs hatch and develop into winged females that disperse to colonize the summer host plants. Once there, females give birth to live offspring that begin feeding almost immediately, and winged and wingless forms may be present at the same time.

If populations become too large or the host plant becomes unsuitable, wing development may occur and dispersal to a better host plant will occur. Multiple generations with all stages of adults and nymphs may be present throughout the summer.

Green peach aphid appears to be predominantly migratory in the Prairies, whereas buckthorn and potato aphids overwinter locally.

Damage/symptoms
Aphid numbers occasionally get large enough to cause direct feeding damage that typically results in an "aphid hole" (an area of the field where feeding damage has caused the plants to collapse due to a removal of plant sap by feeding aphids). More typically, damage by aphids is by the vectoring of damaging plant viruses, especially PVY and PLRV.

PVY symptoms vary with the virus strain and cultivar. Leaves on infected plants are often small and mottled. PLRV symptoms typically include smaller, stunted plants and leathery or stiffer textured leaves that roll inward from the margin.

Both PVY and PLRV reduce crop vigour, resulting in reduced yields. Yield reduction is a function of cultivar, severity and timing of infection and the presence of other stress factors. PVY and PLRV also affect tuber quality, with net necrosis being the predominant symptom.

Control/management
Once plants are infected with either PVY or PLRV, there is no cure. Disease management focuses on controlling the disease spread to new plants.

In table stock potatoes, aphid numbers are typically not sufficient in most years to warrant control. In processing potatoes, aphid management is typically aimed at controlling the green peach aphid (the primary vector for PLRV). In seed potato production, freedom from viral diseases is required to maintain seed certification. Aphid population thresholds are much lower in seed potato fields, and insecticidal control is often applied in this type of production.

Chemical control of aphid vectors works reasonably well for managing PLRV but is not satisfactory for control of PVY. This outcome is a reflection of the way in which the two viruses are transmitted and the time required for transmission.

PVY transmission is almost instantaneous and does not require colonization of the plant; therefore, using insecticides will not completely prevent aphids from transmitting PVY. The use of horticultural oils as foliar sprays has proven to give some degree of protection from the transmission of PVY as the oils either repel the aphids or interfere with feeding.

By contrast, PLRV transmission takes more time and does require colonization. So there is sufficient time for standard insecticides to kill the aphid vector before it has time to spread PLRV.

The best way to minimize the damage caused by aphid-transmitted viruses is by planting clean, virus-free seed. Plant the best quality seed available, using certified seed as the minimum standard. Elite I grade seed or higher is typically planted by commercial producers.

Colorado potato beetle (*Leptinotarsa decemlineata*)

Colorado potato beetle egg mass
Photo: Manitoba Agriculture, Food and Rural Development

Larval stage of Colorado potato beetle
Photo: Manitoba Agriculture, Food and Rural Development

Colorado potato beetle adult
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
The Colorado potato beetle (CPB) pest is common across potato production areas worldwide. The adult is somewhat rounded with a brownish head and thorax and a cream to yellow coloured abdomen with 10 longitudinal stripes on the wing covers (elytra).

Larvae are reddish orange with black markings and range in length from 1 mm (0.04 in.) when newly hatched to 10 mm (0.4 in.) when fully grown. Eggs are yellow/orange and are laid in batches on the underside of leaves and darken just before hatching.

Adults overwinter in soil, typically outside potato fields. However, if rotations are short and resistance to insecticides is abundant, overwintering may occur within fields as well. Adults first appear in late May to mid-June and will feed and mate on newly emerged host plants. Egg laying occurs in late June and through July.

The eggs hatch within 5 to 15 days. The larvae feed on the leaves while going through a series of moults, increasing in size with each moult. The length of time required for the larvae to mature is temperature dependent. Once larval development is complete, the larvae move down into the soil and pupate.

After about 2 weeks, new adults emerge and feed for a short time. Depending on temperature and photoperiod, the adults may mate and begin laying eggs again. However, in the short growing season on the Canadian Prairies, the new larvae will not make it through a complete life cycle, so there is generally considered to only be one complete generation per year, although multiple stages will be present.

Damage/symptoms
Damage is done by both adults and larvae feeding on foliage and defoliating plants. Plants can tolerate about 25 per cent defoliation before any real yield damage occurs, with more tolerance earlier in the season. In general, the insect population required to reach this degree of damage would be about one adult or five larvae/plant.

Control/management

As CPB typically overwinters outside the field, but nearby, greater populations often occur along field margins. In some cases, adequate control can be achieved by simply treating edges of the field with a registered insecticide. A range of insecticide options is available, with some applied with the seed and some applied to the foliage. It is best to make the larval stages the primary target of an insecticide treatment because the adults are difficult to kill.

Resistance to insecticides is often widespread within CPB populations, so use caution when selecting a control option. Proper rotation of insecticides is essential to maintain the efficacy of any insecticide targeting CPB.

Currently, no potato cultivars are resistant to CPB, although the potential for CPB to exceed the damage threshold is greater on cultivars with a small canopy and determinate growth habit.

Rotation is critical and can significantly reduce the number of beetles establishing in a field in a given year. New potato fields should be located at least 200 m (650 ft.) from your past season's potato fields as well as the potato fields of neighbouring producers. This amount of separation can reduce the number of emerging adults that find their way to the new fields (the adults are vulnerable if no host plants are nearby).

Disrupting overwintering areas in field margins by late season tillage can also reduce surviving populations.

Biological control options for CPB are limited.

Flea beetles:

Potato flea beetle (*Epitrix cucumeris*)

Potato flea beetle adult
Photo: Manitoba Agriculture, Food and Rural Development

"Shot-holing" caused by feeding potato flea beetles
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle

The potato flea beetle is very similar in appearance to the tuber flea beetle but has brown legs and antennae. It is also similar in size, shape and colour to many other types of flea beetles. There is only a single generation of potato flea beetles per year, with the adults overwintering in or near potato fields. Larvae feed primarily on roots and root hairs but do not cause economic damage.

Damage/symptoms

Feeding damage is typical of flea beetle species, with shot hole appearance of the leaves as a result of chewing damage by the adults. Damage thresholds are not well understood, although generally, damage in the Prairies is not of economic importance unless the plants are already under stress from drought or attack by other insects or pathogens.

Control/management

Chemical control is rarely necessary, although most products should work well because insecticide resistance is not prevalent in flea beetle populations. An approximate economic threshold is 65 to 75 feeding punctures per terminal leaflet in the lower third of the plant 2 weeks after first appearance of bloom.

Tuber flea beetle (*Epitrix tuberis*)

Tuber flea beetle damage on potato tuber
Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Tuber flea beetle adult and "shot-holing" on potato leaf
Photo: British Columbia Ministry of Agriculture

Tuber flea beetle adult
Photo: E.S. Cropconsult LTD.

Description/life cycle

Tuber flea beetle adults are small, 1.5 to 2.0 mm (0.06 to 0.08 in.) in length, shiny and black. This pest overwinters as an adult in the soil. Adults emerge in mid-May to early June, feeding and mating on potato plants. When disturbed, the adults move rapidly by jumping. Larvae feed below ground on roots and developing tubers. There may be two to three generations per year.

This pest is not known in Saskatchewan and Manitoba at this time, and the degree of effect in Alberta is unclear.

Damage/symptoms

Feeding by adult tuber flea beetles is rarely of economic importance. Larval feeding on tubers is the primary concern as feeding causes several types of damage, including tunnelling in the tuber, channels on the surface and pimpling. The tunnels and channels may provide access points for pathogens to enter the tuber.

Control/management

Early season control of adults is most effective, as it reduces the need for control later in the season. Crop rotation can be beneficial.

Leafhoppers:

Aster leafhopper (*Macrosteles quadrilineatus*)

Description/life cycle

The life cycle of the aster leafhopper is described in Aster Leafhopper in the Carrots section. These pests are seldom a problem in potatoes unless their numbers are very high and their infectivity with aster yellows is also quite high. However, they are a concern for seed potato production.

Damage/symptoms

Aster yellows in potatoes is often referred to as purple top, and the disease may cause wilting of potato foliage if the infection is serious.

Control/management

If numbers and infectivity warrant, the application of insecticides may be necessary but is rarely the case for producers other than seed producers. Seed producers need to be vigilant to keep aster leafhopper populations in check to reduce the probability of having aster yellows infect their seed potato crop.

Potato leafhopper (*Empoasca fabae*)

Nymph of potato leafhopper
Photo: Frank Peairs, Colorado State University, Bugwood.org

Description/life cycle

The potato leafhopper is a migrant to Canada, overwintering in the Gulf States. Typical wind and migratory patterns push this pest more to the east. It is typically found in low, non-economical levels in Manitoba in most years, but a significant population arrives every 5 to 7 years in this region and less frequently further west.

Potato leafhopper adult
Photo: Steve L. Brown, University of Georgia, Bugwood.org

The potato leafhopper adult is similar in size to the aster leafhopper adult, but the potato leafhopper is bright green. Adults are very active and fly readily. Nymphs move rapidly on leaf surfaces, distinguishing them from slower moving aphids. The nymphs often move to the other side of the leaf when disturbed. Nymphs are similar in appearance and colour to adults but do not have wings. There is usually only a single generation per year in the Prairies.

Damage/symptoms

Damage to potatoes depends on a number of factors including plant staging, duration of feeding and density of leafhoppers. Adults and nymphs both feed by puncturing plant tissue and sucking juices out of the plant. Feeding damage is often referred to as "hopper burn." Damage first shows up as yellowing at the tips and margins of leaves, and progressively worsens, with the leaves rolling inwards and eventually dying.

Control/management

In most years, management of potato leafhoppers is not necessary, although low levels may be present each year. The only viable option when populations are sufficiently high is chemical control. Choose insecticides that are effective against potato leafhopper but will not enhance selection pressure for insecticide resistance in Colorado potato beetles.

White grubs, June beetles (various *Phyllophaga* species)

Larval stage of white grubs
Photo: Steven Katovich, USDA Forest Service, Bugwood.org

Description/life cycle

Adult beetles are brown, 20 mm (0.8 in.) long and 11 mm (0.4 in.) wide. They are active, nocturnal flyers, often attracted to lights. Larvae are typically c-shaped grubs with 3 obvious legs and a brown head, reaching a length of 30 mm (1.2 in.) when fully grown.

The life cycle is typically 3 years, with adults laying eggs in soil in June (typically) and larvae hatching about a month later. Initially feeding on decaying vegetation, they cause little damage in the first year and overwinter in the soil as second instar larvae. The following year, they resume feeding in June in the third instar stage on available plant hosts, including potato tubers and roots. They cause the most injury at this time.

Damage/symptoms

Damage is most common in areas where the ground was previously in or near sod. Larvae feeding on the roots will cause stunting and wilting. When the larvae feed on the tubers, they may excavate large cavities, rendering tubers unmarketable.

Control/management

Avoid recently cultivated sod. Treatment with insecticides is difficult, as the grubs are underground.

Wireworms (various species)

Description/life cycle

Wireworms are the larval form of click beetles (Elateridae family). The adults are narrow, brown to black beetles from 5 to 20 mm (0.2 to 0.8 in.) in length. The larvae are pale creamy to rusty brown, slender and cylindrical, with three legs near the head. The larvae are 20 to 30 mm (0.8 to 1.2 in.) long at maturity.

More detail and an image of wireworm are in the Common Insect Pests section of the Pest Management chapter.

The life cycle is variable depending on the species and can take 2 to 5 years to complete. Larvae can survive extended periods without feeding. Larvae move within the soil to feed on roots or seeds, or tubers in the case of potatoes.

Damage/symptoms
Wireworm damage is entirely from the larval stage as they tunnel into tubers. There is no reduction in tuber weight generally, but obvious signs of wireworm feeding can significantly reduce tuber quality, often rendering the tubers unmarketable.

Feeding may also cause the deformation of new tubers, and in severe instances, the feeding may cause plants to weaken and stands to appear spotty. This situation is uncommon in the Prairies.

Control/management
Rotation, on its own, is typically of limited value in reducing wireworm problems, as the pest's life cycle is long, and larvae can survive extended periods without feeding. Avoid planting potatoes into newly turned sod.

The use of canola or alfalfa in rotation may aid in reducing populations, but these crops must remain in rotation for periods of 3 to 4 years. Rotations with cereal crops will not reduce wireworm problems. Producers should scout fields for wireworm problems a year ahead of planting potatoes.

A limited number of insecticidal controls are available. Seed treatments may be applied to control wireworms in rotation crops. Seed treatments or in-furrow treatments may be used to manage wireworm problems in potato crops.

Disease management

Bacterial ring rot (*Clavibacter michiganensis subsp. sepedonicus*)

Rotting vascular system in potato tubers caused by bacterial ring rot
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Bacterial ring rot is a very serious disease of potatoes and has been detected in all major potato production areas. This disease is very infectious and destructive and is of concern for both table and seed potato producers. Entire crops can decay rapidly in storage, resulting in very severe losses.

Foliar symptoms of bacterial ring rot
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Severe bacterial ring rot tuber damage
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

In Canada, ring rot outbreaks are to be eradicated, as the presence of this pathogen can have very detrimental effects on seed production and trade. Stringent seed certification procedures have reduced the frequency of outbreaks.

Damage/symptoms
Above ground symptoms can vary with cultivars and are not usually observed until after flowering. Symptoms are typically first observed on the middle to lower leaves, with leaflets wilting and exhibiting a slightly rolled margin. A light green to pale yellow area may develop between the veins.

Tuber symptoms appear as a ring of pale yellow to light brown cheesy rot when the tuber is cut in cross section. An odourless ooze of bacteria can leak from the vascular ring. As infections develop, the vascular ring will detach from the rest of the tissue. Tuber surfaces may become cracked and sunken. Opportunistic organisms can exploit the decay caused by the ring rot pathogen, leading to further breakdown. Complete degradation of the potato can occur in the field or in storage.

Control/management
There is zero tolerance for this disease in potato production. Always follow strict sanitation measures in every part of your potato operation to prevent this disease. If ring rot is detected in your operation, make eradication the first priority, and inform the Canadian Food Inspection Agency (CFIA) as this disease is a regulated pest and can affect exports to many countries.

ALL growers are strongly advised to use only certified seed or higher class disease-free tubers. Avoid using resistant cultivars with high immunity because they could be symptomless carriers. Plant whole seed potatoes, if available. If cut seed is being used, disinfect cutting knives frequently using an approved disinfectant. Plant with a cup-type planter instead of a pick-type planter.

Always wash all storage areas and all machinery involved in potato handling, harvesting, grading and any other part of the potato production process (such as cutting knives) with a high pressure spray, and disinfest with formaldehyde, commercial bleach or quaternary ammonium (approved disinfectants).

Continue to wash and disinfect all equipment daily after use and always between seed lots, when planting. Dispose of all used potato bags. Employ a three-year rotation and destroy any volunteer potato plants.

Do not grow sugar beets in the same field for at least 3 years as they are susceptible to bacterial ring rot. Tomatoes have been found susceptible under lab conditions but not in the field.

The Colorado potato beetle and the green peach aphid have been implicated as additional means of disseminating the bacterium.

Bacterial soft rot (*Erwinia carotovora* subsp. *carotovora*)

Bacterial soft rot damage
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
This bacterial disease can survive for months in soil and can be spread through irrigation water. Typically, the pathogen enters the tuber via wounds from cutting knives or other equipment, insect injury or damage from freezing. Tubers in early development tend to be more susceptible. High temperatures and moist soil conditions can also facilitate disease development.

Poor storage conditions that promote humidity and insufficient ventilation can add to the problem. Placing infected potatoes in plastic bags for shipping or marketing can lead to rapid breakdown of the tubers.

Damage/symptoms
Symptoms usually develop on tubers. The pathogen is often a secondary organism, exploiting damage caused by bacterial ring rot, late blight, potato leak, blackleg and mechanical injury.

Initially, a brown, sunken lesion may occur. Depending on the pre-existing damage, the entire tuber may be compromised by the secondary bacterial soft rot infection. Infected areas are cream coloured and have a foul, pungent odour. This odour can be used to distinguish soft rot from various other bacterial diseases. Well defined margins separate the diseased tissues from healthy tissues within the tuber.

Prolonged moist growing conditions can result in the spread of tuber infection in the field. Rotting tubers can pass on the bacterium to other tubers, making harvest extremely difficult and requiring extensive cleaning operations.

Control/management
Grow potatoes in well drained, properly fertilized soils. Only harvest mature tubers. Top-kill (desiccate) vines to speed up maturation.

Potatoes intended for packaging immediately after harvest should be dug when soil and air temperatures are low enough to cool the tubers. When washing, take care to change the water frequently, as the bacteria can be easily spread through contaminated water.

This disease problem usually develops as a result of a predisposing condition. Good techniques for managing the other tuber diseases associated with soft rot will generally reduce outbreaks.

Blackleg (*Erwinia carotovora* subsp. *atroseptica*)

Dry stem lesions caused by blackleg
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Blackleg of potato is caused by a group of bacterial pathogens capable of causing significant damage and heavy losses in crops. Seed handling procedures, the amount of pathogen on seed tubers, soil moisture and temperature conditions at planting as well as cultivar selection can all have a significant effect on disease development.

Wet to saturated soils and temperatures of 18°C (64°F) or higher favour the pathogen. Young tubers are more susceptible than those with mature skin.

The bacterium can be dispersed via irrigation systems and through the use of infested tools during seed cutting. Slow wound healing can also promote the disease. The pathogen can move in soil water; therefore, decaying stems and tubers may contaminate other tubers during harvest.

The roots of weeds such as nightshade, lamb's quarters, pigweed, Russian thistle, kochia, purslane and mallow are all potential hosts for the pathogen.

Tubers can continue to rot in storage, as lenticels can harbour the bacteria. Discarded tubers are an important source of the bacterium, and insects associated with cull piles can potentially move the bacterium to new plants.

Damage/symptoms

The initial symptoms appear at flowering when a stem begins to wilt, usually accompanied by yellowing of the leaves. The lower portions of the stem appear black and "oily" from the soil line to about 15 cm (6 in.) up the stem.

The plants may appear stunted. A light vascular discolouration of the stem, progressing to a complete soft rot infection, typically starts at the stem end of the tuber and appears as a creamy, odourless, soft decay. Diseased areas are sharply demarcated from the healthy tissues by a dark brown to black margin. In very moist conditions, lenticels may be surrounded by sunken, water-soaked circular lesions.

This disease often is first observed in low areas of the field that are poorly drained or slow to dry after irrigation or rainfall.

Control/management

Plant whole seed that is free of blackleg. Potatoes should be planted in moist, well drained soil that is at 10°C (50°F) or higher. Allow tubers to mature before harvesting.

Clean and disinfect potato storage areas annually and potato equipment as often as is feasible. If using cut seed, be sure to clean and disinfect cutting equipment frequently. Remove rotted tubers from seed stocks during grading. Culled potatoes and vegetables should be properly composted, buried, or used as feed for livestock.

Keep potatoes free of insects that could spread the bacterium.

Black scurf, Rhizoctonia canker (*Rhizoctonia solani*)

Black scurf lesions on potato tubers
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Knobby, malformed tubers as a result of *Rhizoctonia* infection
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle

Rhizoctonia-related diseases are common wherever potatoes are grown. The initial source of the fungus may be derived from seed- or soil-borne sources. When seed infected with *Rhizoctonia solani* is planted, developing sprouts, stolons and roots may become infected early in development.

In the soil, the fungus can overwinter as sclerotia (black scurf) on tubers in the soil or in the soil itself or as mycelium on crop residues. Mycelium from sclerotia can grow into emerging plant tissues as well.

High temperatures early in the season will reduce damage associated with *Rhizoctonia solani*, whereas low temperatures can lead to significant damage.

The formation of sclerotia is related to tuber maturation, usually developing later in the season. The fungus may survive for long periods as a saprophyte, colonizing plant residues, not only potatoes.

Damage/symptoms
Sclerotia (black scurf) is the "dirt that won't wash off," appearing much like soil on diseased tubers.

Infected plants may fail to emerge completely. Reddish brown discolouration of roots and stem as well as stolon cankers may occur. Other symptoms include swollen stems, aerial tubers, rolling, wilting and purpling of the leaves, premature death of the vines and tuber malformations.

In the field, grey to white, felt-like mycelium on stems may be observed at the soil surface.

Aerial tubers found on stems infected by black scurf
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Control/management
Ploughing down a green cover crop the year before planting potatoes can help reduce disease levels if black scurf has been a problem in previous years. Maintain a three-year rotation as even low levels of the pathogen can lead to severe outbreaks. Rotate with cereals and grasses. Avoid growing potatoes in fields or portions of fields where the disease has been severe in past years.

Plant seed that is free of sclerotia. Avoid planting in cold, wet soil, and cover seed pieces with not more than 5 cm (2 in.) of soil. Promote rapid emergence by planting in warm soil, shallow seeding and hilling after emergence. Warming seed can accelerate emergence and will reduce the likelihood of stem cankers and sprout damage.

Harvest tubers as soon as they are mature. In small plantings, hand pulling of tops to remove stems, stolons and roots just before harvest may help reduce black scurf.

Fungicides may help control seed-borne *Rhizoctonia solani*, but may be ineffective in highly infested soils.

Common scab (*Streptomyces scabies*)

Common scab lesions
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Common scab has little effect on yield, but can greatly affect grade and cooking quality.

The pathogen can survive as a saprophyte on decaying plant residue. It can also survive in living roots and manure. It tends to be a problem in alkaline soils. Wind-blown rain and soil can spread the pathogen to new fields.

Infection may occur through lenticels in the first 5 weeks of tuber formation. If tubers become excessively dry, any organisms that fight scab attacks will vanish from the lenticels, so the pathogen will be able to colonize the lenticels more easily.

Soil temperatures of 20 to 22°C (68 to 72°F) are optimal for the disease's development. Common scab may develop slowly at 11 to 13°C (52 to 55°F) and at or above 30°C (86°F).

Scab lesions do not develop in storage.

Streptomyces scabies also affects beet, carrot, parsnip, rutabaga, turnip and radish, but damage is not as severe on these crops.

Damage/symptoms

Symptoms initially appear as round, irregular lesions less than 10 mm (0.4 in.) wide, occurring across the tuber surface. These symptoms progress to shallow, corky areas with erupting lesions. Then, they later develop into deeply pitted areas with dark brown lesions up to 6 mm (0.24 in.) deep.

Disease severity can range from a few spots to total tuber coverage.

Control/management

To manage common scab, it is critical to maintain adequate soil moisture, especially at tuber initiation and set as this problem tends to occur more in drier soils.

Maintain a three- to five-year crop rotation, preferably including legumes. Avoid other susceptible crops in the rotation (see above). Plant scab-free seed on land free of scab. Seed treatment fungicides may help lessen the effect of tuber-borne scab.

Use acidic fertilizers such as ammonium sulphate (21-0-0), and avoid practices that raise the soil pH to alkaline conditions.

Manure from animals fed scab-infected tubers and roots should not be used on land to be sown to susceptible crops.

Well-rotted organic matter helps promote soil moisture and reduces the occurrences of dry conditions that favour scab.

Early blight (*Alternaria solani*)

Early blight leaf lesions; note "bull's-eye" appearance and characteristic limiting of lesions by leaf veins
Photo: R.J. Howard, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle

Early blight can also cause problems on tomato, pepper, eggplant and many solanaceous weeds (i.e. weeds in the same family as potato, such as nightshades). The fungus persists on infested crop residue, infected tubers and on other solanaceous plants. *Alternaria solani* spores can move to leaf surfaces either by direct contact between the leaves and infested residues or by rain or splashing water.

Foliar lesions are typically first observed at or near the time of flowering. Water splashing can spread the pathogen from infected to healthy tissue, and repeated cycles of infections can occur through the season.

Field-wide devastation caused by early blight
Photo: R.J. Howard, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Optimum temperature for infection is 20°C (68°F). At temperatures above 27°C (81°F), infections are halted. Cool nights and heavy dew favour development of the disease. Early senescence may occur if the plants are nitrogen-deficient or if plants are experiencing drought or others stresses (e.g. other diseases).

Tubers can become infected when pulled from soil contaminated with *Alternaria solani* spores. High levels of foliar blight will increase the amount of spores on the soil surface. Harvesting immature tubers may increase the risk of infection as these tubers are prone to skinning, which creates open wounds and entry points for the pathogen.

Damage/symptoms
Lesions appear on upper leaves and stems. Initially, small, brown, pinhead-like dots appear on older leaves. As lesions expand, they become circular, or somewhat angular if delimited by leaf veins. Lesions appear as concentric rings of dead tissue, roughly 3 to 10 mm (0.1 to 0.4 in.) across, giving them the classic “bull’s-eye target” appearance. Yellow concentric rings bordering the lesions may also be visible, while leaves are green.

Diseased leaves do not usually fall off. Young leaves on plants under a high nitrogen regime do not usually express symptoms.

Tuber symptoms can appear during storage. Infections appear as dark, depressed, circular regions surrounded by uplifted borders. These regions may increase in size during storage. Where lesions penetrate into the tuber flesh, they appear leather-like and superficial.

Control/management
Use seed potatoes that are free of the disease. Maintain soil moisture and fertility to encourage healthy plant growth. Remove and then burn or bury severely diseased vines. Avoid growing potatoes, tomatoes or eggplants in the crop rotation for at least 2 consecutive years.

Several foliar fungicides are registered for control of this disease. Spray the foliage with a fungicide when the disease appears and continue at 10-day intervals or frequently enough to prevent the disease from becoming severe. Allow tubers to mature fully before harvest. Avoid any mechanical injury.

Fusarium dry rot (*Fusarium avenaceum, Fusarium sambucinum*)

Early stage fusarium dry rot; note wet appearance of early stage rotted tissues
Photo: Robert Spencer

Late stage fusarium dry rot
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Fusarium dry rot is a serious post-harvest disease of potato and is common anywhere potatoes are produced. Cereals, grasses, fruits, vegetables and ornamental host crops may also be attacked by the causal organisms, although disease symptoms will vary. Invasion of other decay organisms can cause further damage. These fungi can survive for many years in the soil.

Most infections originate from infected seed tubers. Infections can occur when tubers are wounded during harvesting, grading or seed cutting. If tubers are infected during cutting, they can turn brown under moist conditions, and soft rot bacteria can invade rotted areas. In the field, an infected seed piece can break down completely, resulting in missing plants. The fungus may infect young plants, or it may end up within soil particles and clumps that are harvested with the crop.

These species of *Fusarium* cannot infect intact tuber skin, lenticels or suberized seed pieces. Tubers with well developed skins and no wounds are resistant to dry rot. Damp storage conditions favour the development of dry rot.

Damage/symptoms
The first dry rot symptoms appear about a month into storage, developing near wounds. Shallow lesions are visible as small brown areas. As the disease develops, large, sunken concentric rings, which collapse under light pressure, may form on the tuber. Infected tissues may be tan to black and are very dry in the absence of other decay organisms such as soft rot.

Completely decayed tubers become shrivelled and mummified. The spaces beneath the decayed portions are usually lined with a light pink-tinted mycelial growth.

Control/management
Treat cut seed with a fungicide seed treatment, and plant seed immediately into warm, moist soil.

Harvest during dry, cool conditions to avoid bruising and wounding. Recently harvested tubers should be stored for 7 to 10 days at 12°C (54°F) to promote wound healing. Keep storage at 90 per cent relative humidity with adequate air circulation.

Late blight (*Phytopthora infestans*)

Coppery brown dry rot of internal tissues, typical of tubers with late blight
Photo: Courtesy R. C. Rowe; Reproduced, by permission, from Rowe, R. C. 1993. Potato Health Management. American Phytopathological Society, St. Paul, Minn.

Late blight lesions; note water-soaked appearance and lesions are not contained by leaf veins
Photo: Dr. K. Al-Mughrabi

White "downy mildew" of sporangia and sporangiophores of *Phytophthora infestans* at the margins of necrotic leaf lesions on underside of leaf
Photo: Courtesy R. V. James; Reproduced, by permission, from Stevenson, W. R., Loria, R., Franc, G. D., and Weingartner, D. P. 2001. Compendium of Potato Diseases, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Late blight induced dieback of potato tissue
Photo: William E. Fry, Cornell University

Description/disease cycle

Late blight is a problem virtually anywhere potatoes are produced and is one of the most serious diseases affecting potatoes worldwide. While outbreaks are relatively uncommon on the Prairies, this disease forms the basis for most disease control programs in potato production. Recognition of the damage it can cause has led to the development of a number of disease forecasting methods to time fungicide applications.

The late blight pathogen can infect other solanaceous plants such as tomato and various nightshade weeds. Some strains of the pathogen are potentially more devastating to potato than tomato and vice versa.

The pathogen can overwinter in living potatoes in Canada and persists in seed tubers, cull piles or volunteer potatoes that overwinter in the field. Air-borne sporangia can be transported considerable distances.

The spores can germinate directly and initiate infections immediately, or they can go through a second, water-borne state known as zoospores that penetrate host tissues. Once the penetration of leaves occurs, disease development is most rapid at 21°C (70°F).

Damage/symptoms

The first symptoms on older leaves appear subsequent to flowering when humid weather occurs. Dark green, water-soaked areas at the leaf tips move inward and become dark brown and brittle in 1 or 2 days. The underside of infected leaf lesion edges may appear fluffy during periods of high humidity. Late blight lesions may appear similar to early blight lesions initially; however, late blight lesions are not contained by the leaf veins.

Late blight lesions produce masses of spores, which are spread by rain and wind to other plants. Under ideal conditions, a disease outbreak will occur very quickly, resulting in defoliation, plant death and yield losses.

Spores produced on the foliage may be washed into the soil. The spores can move in the soil water to infect tubers at or near the soil surface. Lesions on the surface of tubers appear irregular and depressed and are often near the eyes. Diseased tissue is granular and reddish and may penetrate up to 2 cm (0.8 in.) into the tuber.

The storage of diseased tubers can result in infection of other tubers, causing heavy losses.

Control/management
No cultivars are resistant to late blight. Preventive fungicide applications are required to manage this disease, especially if late blight has been reported within your area or in nearby areas. Apply registered foliar fungicides at 7- to 10-day intervals until foliage senesces.

Potato tops should be killed (mechanically or chemically) 2 weeks before harvest to reduce tuber infection late in the growing season. All cull piles should be destroyed, tubers deeply buried and volunteers promptly destroyed.

When using sprinkler irrigation, consider the effect of irrigation on disease spread as well as the duration of leaf wetness, especially as canopies become dense. Options to minimize leaf wetness duration could include applying irrigation water in the morning to encourage leaf drying and/or possibly applying heavier but less frequent irrigation applications.

Mosaic potato viruses A, S, X, Y

Symptoms of plants grown from potato leafroll virus-infected tubers; note the rolled and leathery leaves
Photo: Reproduced, by permission, from Rowe, R. C. 1993. Potato Health Management. American Phytopathological Society, St. Paul, Minn.

Mosaics are the most frequently occurring virus-induced diseases on potato in Canada. Effects can vary from virtually symptomless plants to significantly damaged plants. All the viruses outlined in Table 31 will overwinter in infected tubers.

Table 31. Potato virus symptoms and spread

Virus	Symptoms observed	How is it spread?	Management
Potato virus A	Leaf mottling and mosaic; no tuber symptoms	Potato aphid or green peach aphid	Use certified seed
Potato virus S	Almost symptomless; deepening of veins; mottling or bronzing of foliage; no tuber symptoms	Cutting knives; sprout contact; foliage rubbing together	Use certified seed; clean cutting knives between seed lots
Potato virus X	Mottling of foliage; no tuber symptoms	Cutting knives; sprout contact; contact of foliage or roots during the growing season; biting and chewing insects, but not aphids	Plant pedigreed seed; disinfest machinery and cutting knives between seed lots
Potato virus Y	Mild mottle to foliar necrosis; some strains produce brown rings on the tuber skin	Winged aphids - green peach aphid most efficient, buckthorn aphid also a concern	Control aphids; use horticultural oils; use selected seed of certified or higher class

Symptoms of infection by potato virus Y strain O (PVYO) in potato: mosaic
Photo: Reproduced, by permission, from Rowe, R. C. 1993. Potato Health Management. American Phytopathological Society, St. Paul, Minn.

Powdery scab (*Spongospora subterranea*)

Tuber lesions caused by powdery scab
Photo: R.J. Howard, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Powdery scab galls on nightshade
Photo: Clive Schaupmeyer

Description/disease cycle

This disease develops in damp and cool (11 to 18°C; 52 to 64°F) environments. It can cause damage on its own as well as serving as a vector of potato mop-top virus, a serious quarantine pathogen.

The powdery scab pathogen has a complex life cycle that involves resting spores and a mobile water-borne stage known as zoospores, which infect root hairs. Resting spores are produced on plant tissues and then germinate, giving rise to new zoospores.

The pathogen survives as resting spores and may be moved in contaminated soil and on tubers. This process can repeat multiple times in a year, leading to multiple infections. The resting spores can survive for up to 6 years. *Spongospora subterranea* can also complete its life cycle on other solanaceous crops, including peppers, tomatoes and nightshade weeds.

Damage/symptoms

This disease first appears as purplish brown, sunken lesions. Later, the lesions become scabby or warty on tuber surfaces and are filled with dark brown, powdery masses of spore balls, each containing many spores. Powdery scab lesions are similar to common scab lesions, but are rounder and smaller. Distinguishing between powdery scab and common scab by visual diagnosis is very difficult.

In storage, potatoes infected with powdery scab become dry and shrivelled up.

Control/management
Do not plant potatoes into fields known to be infested with powdery scab. Plant symptom-free seed produced in areas free of powdery scab to prevent introduction into previously clean fields. Do not use manure that has come from animals that have fed on infected tubers.

Crop rotations may have to be as long as 10 years, but generally a 3- to 4-year rotation away from solanaceous plants is recommended. Avoid planting potatoes in poorly drained fields. Carefully manage irrigation water, being certain not to over-irrigate or allow contamination of the water with powdery scab.

Control nightshade and other solanaceous weeds, and prevent them from growing in fields that have been infested with powdery scab.

Purple top (aster yellows phytoplasma)

Aerial tuber on a potato plant infected with phytoplasma
Photo: Reproduced, by permission, from Rowe, R. C. 1993. Potato Health Management. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
This pathogen affects a wide range of hosts. It is only transmitted by leafhoppers; therefore, potato infections depend on the availability of other hosts. The pathogen develops within the host and the insect vector. Environmental conditions that promote the growth and dispersal of the leafhopper can increase the likelihood of disease outbreaks.

Damage/symptoms
Upper leaflets may appear to have rolled margins and will produce a purple or yellow pigmentation. Below-ground tubers may be soft and spongy. Affected stems usually die early in development, preventing tubers from reaching maturity. Tubers may form above ground in any part of the canopy. This unusual symptom can be quite visible. The phytoplasma organism rarely survives in tubers.

Seed crops infected during development by aster yellows (AY) do not produce high vigour seed and have reduced tuber size.

Control/management
The use of carefully selected certified seed grown in areas where AY is rarely found is important. Growers in areas where AY is widespread should use insecticides to control leafhoppers that migrate into potato fields, especially at margins. See the information on aster leafhoppers earlier in the Potatoes section and in the Carrots section.

Pythium leak, potato leak (*Pythium ultimum*, other *Pythium* species)

Pythium leak damage of potato
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Leak can occur wherever potatoes are produced. Symptoms may be observed at any stage of production, from planting to storage. Injuries during harvest or any handling operation can predispose tubers to potato leak.

Pythium can be long lived in the soil and can attack a wide range of plants. *Pythium ultimum* enters tubers through wounds. Potatoes can be infected through cut surfaces or bruises during harvest, and significant losses may occur when harvesting occurs during hot weather (25 to 30°C; 77 to 86°F), particularly if tubers are handled poorly. If crops are stored at high temperatures with poor ventilation, high levels of decay can result. Temperatures below 10°C (50°F) are not conducive to disease development.

Pythium ultimum has a wider host range than other *Pythium* species. Forms of the pathogen that cause disease in potatoes have also caused disease in carrots and beets.

Damage/symptoms
Only tubers are affected by this pathogen. Disease development begins at bruised or cut areas where light to dark brown lesions may appear, especially near the stem end. Water may flow out of the tubers. Internal diseased tissue is granular and cream coloured initially, and then becomes grey to black. Diseased tissues have a clearly defined margin from healthy tissues.

As the disease develops, rotted tissues lose integrity, becoming spongy and wet with air spaces. In as short a time as 1 week, a severely diseased tuber may be so badly decayed that even minimal pressure can cause the tuber to ooze liquid. In storage piles, tubers may remain in the piles as hollowed out papery skins with virtually no fleshy tissue.

Control/management
The crop should be allowed to reach maturity before harvest to minimize any mechanical injury during harvesting, grading and storage procedures. Encourage good skin set through top-killing vines before harvest. It is critical to ensure that all tubers are handled carefully to minimize any damage.

Harvest during cool weather. If the crop must be harvested in warm weather, immediately cool the tubers and promote air movement to speed up the drying process. If possible, harvest during the coolest part of the day. Do not leave potatoes exposed to the sun for extended periods as disease susceptibility increases.

Try to avoid growing potatoes on poorly drained fields. Crop rotation and destruction of diseased tubers are necessary to reduce pathogen levels in the soil.

Silver scurf (*Helminthosporium solani*)

Silver scurf lesions
Photo: I.R. Evans, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Silver scurf is a soil-borne fungus. It is prevalent in many potato producing areas. The fungus can be transported on seed pieces and can survive on tuber residues in the soil. Clean seed can become infected when planted in infested soil. Tubers may be infected through lenticels or periderm tissue.

Mature tubers left in the field late in the season in warm, moist soil are also susceptible to infection, and if left in the field too long will increase in disease severity. Infection levels can increase in storage at temperatures above 3°C (37°F).

Damage/symptoms
Round, light brown or grey leathery spots form on the tuber, potentially growing to cover most of the tuber surface. When the tuber surface is wet, an infected tuber will have a white to silver sheen. Masses of spores give the tubers a dusty or sooty appearance. Spore-bearing structures resemble tiny Christmas trees. This disease is most apparent on red cultivars, as lesions discolour the tuber skin.

In storage, the infection increases moisture loss, which can lead to tuber shrinkage. Severe infections may penetrate deeply into the tuber, making the symptoms difficult to remove during peeling operations.

Control/management
Rotations away from potato are important to managing this disease as this pathogen does not infect any other crops. Soil-borne inoculum is likely to decrease over time, away from potato crops.

Avoid the use of heavily infected seed lots. Treat seed with a registered fungicide before planting to reduce the spread from infected tubers.

Tubers should be harvested when mature, but not left in the field for too long, if possible.

Before storage, potatoes may be treated with a registered fungicide. Ventilate the storage with dry, warm air to remove moisture and condensation from the tubers. Store at as low a temperature as possible without freezing.

Storages should be cleaned, pressure washed and treated with a disinfectant before newly harvested tubers are placed into storage.

Weed management

Weeds in potatoes reduce yields and interfere with normal field operations such as hilling, spraying, roguing (culling) and harvest. Weeds are also alternate hosts for various insect and disease pests of potatoes.

Weed management is important in potatoes from the time of planting until plants are well established or rows close. Once the potato canopy has closed, any emerging weeds will be shaded out. Control perennial weeds before planting. Tillage (including hilling) can reduce the effect of most annual weeds. Selective application of chemical herbicides (pre-plant, pre-emergent or post-emergent) can also provide adequate weed control.

Potatoes are very sensitive to herbicide residues in the soil, whether from application to past crops or introduction in manure, compost or water. Adjust potato rotations to allow sufficient time for soil residual herbicides to break down. Some herbicides are not compatible with potato rotations. See Table 26 in the Pest Management chapter for herbicide lifespans.

Other requirements

Seed selection

Many diseases that reduce potato yields are carried from year to year and are introduced into new areas/fields through the planting of infected seed. Many of these diseases do not produce visible symptoms on the outer surface of the tubers; this is particularly true of bacterial and viral diseases. Therefore, planting good quality, inspected certified seed is crucial.

Characteristics of high quality seed are trueness to variety, freedom from seed-borne diseases and physical soundness. The seed should have been produced under suitable growing conditions and stored at temperatures of 3 to 5°C (37 to 41°F).

Hilling

The basic reason for hilling potatoes is to keep the developing tubers covered to prevent sunburn and greening and to protect the potatoes from fall frost. Hilling can also improve soil moisture retention.

Early cultivation is desirable to control germinating weeds and to provide loose soil for later hilling operations. At planting, create a small hill over the seed piece. The number and timing of subsequent hilling operations depends on the equipment used, field conditions, weed pressure, etc.

Remember that each hilling operation has the potential to cause soil compaction and root pruning; avoid unnecessary tillage. Complete all hilling operations before row closure to prevent damage to the plants.

Top-killing (desiccation)

Killing and/or removal of the vines before harvest accomplishes several objectives:

- hastens maturity, thereby improving skin set and tuber maturation
- facilitates mechanical harvesting as the dead and dry vines do not clog up harvesting equipment
- prevents movement of leaf diseases to the tubers

Top-killing also increases the dry matter content of the tubers if the tops die slowly. Vigour of the tops as harvest time approaches will depend on the length of the growing season and the potato variety. Some early maturing varieties may die down naturally before harvest. Later maturing varieties may not die down naturally before harvest; these varieties will require some form of vine killing procedure.

Top-killing can be done chemically or mechanically. Mechanical and chemical vine killers can be used alone or in combination. Flail-type mechanical beaters kill vines instantly. These machines must be adjusted carefully to minimize tuber injury.

Chemical top-killers are applied to the foliage and only kill the tops. The speed of killing by chemicals depends on several factors: foliage density, vine vigour, the amount of chemical applied, the quality of leaf coverage achieved, temperature and the characteristics of the chemical product. Only use products registered for top-killing.

Top-killing should be done 10 to 14 days before the desired harvest date. Depending on vine vigour, more than one application may be required. The treatment should be delayed as long as possible to increase yield.

If you are planning to spread out your workload by harvesting only a portion of your potato crop at a time, consider also staging the top-kill treatment to match that timing and allow the further growth of unharvested plants.

Mechanical injury

Mechanical harvest injuries result in large economic losses annually to potato growers. Bruises are not always noticeable at harvest, but may show up in or after storage and result in heavy losses by increasing moisture loss and disease, lowering the grade and increasing the number of culls.

Give special attention to the proper adjustment and calibration of all conveyors and drops within all pieces of equipment used to harvest and handle potatoes. The addition of padding and careful attention to drop heights throughout the handling process can reduce injury. Machine operators

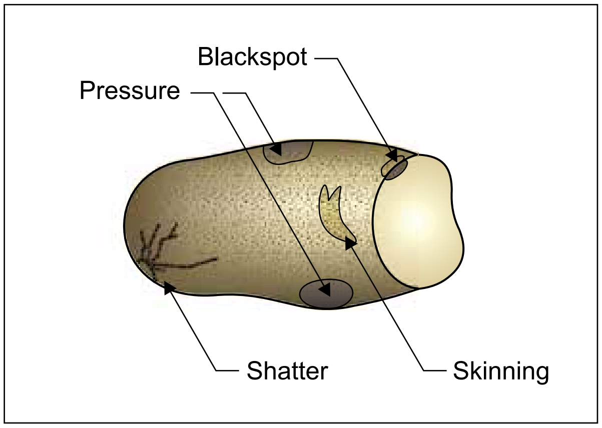


Figure 8. Examples of mechanical injury and bruising

need considerable expertise and constant alertness to optimize machinery performance while minimizing potato damage.

Soil temperature and moisture are also important factors in minimizing mechanical injury. Blackspot bruising is more likely to occur under warm, dry soil conditions. Irrigation before harvest can reduce blackspot bruising. Shatter bruising is more common under cooler, wetter conditions. Completing harvest as early as possible and when temperatures are above 7°C (45°F) can reduce shatter bruising.

Sprout inhibition

Year-round marketing of potatoes has become a reality with the development of modern cold storages and effective sprout inhibitors. The use of sprout inhibitors for table and processing potatoes is necessary due to the requirement for higher storage temperatures (to prevent post-harvest reductions in quality) for these varieties. Similarly, sprout inhibitors are required for table potatoes because of a preference for short dormancy cultivars.

Sprout inhibitors should be used in conjunction with, rather than as a replacement for, good storage management practices. The correct application and timing of registered sprout control products are critical. Some sprout inhibitors are applied as a fog to the stored product whereas others (e.g. maleic hydrazide) are applied to the plant about 2 weeks before top-killing. Consult labels for directions or hire a competent professional for assistance.

CAUTION: Do not use sprout inhibitors on or near potatoes to be used for seed. Even in small quantities, these inhibitors will adversely affect germination of the seed. Do not store seed potatoes in storages that have been treated with sprout inhibitors in the past.

Harvesting

The decision as to when to dig potatoes is influenced by considerations such as market prospects, suitable weather, level of mechanization and the availability of labour. The proper time for harvesting potatoes should be determined chiefly by the maturity of the crop.

A wide range of different equipment types exists for harvesting potatoes.

Generally, potatoes are ready to be harvested once vines have been dead for 7 to 14 days. This timing will ensure that the crop is fully matured before harvesting, with the skin of the tubers set, which reduces the likelihood of skinning and bruising.

Even when harvesting a mature crop, however, take care to prevent mechanical damage. Preventive practices can include padding the chains and elevators on the harvester, providing a constant flow of potatoes and soil on all chains, operating at appropriate speeds, harvesting at correct soil moisture and temperature, and handling the potatoes carefully. Drop heights should be kept to less than 30 cm (12 in.), preferably closer to 15 cm (6 in.).

Avoid harvesting when internal tuber temperatures are less than 7°C (45°F) or above 18°C (65°F). Harvesting at warmer temperatures will generally result in a higher incidence of blackspot bruising as well as more storage rots (e.g. bacterial soft rot). Harvesting at lower temperatures can result in more shatter bruising.

Quality potatoes are turgid, brightly coloured, uniform in shape and size, and free from disease, damage and other deformities. Potatoes are stored dirty to reduce water loss; therefore, some dirt may be attached to potatoes before and during storage.

Too much dirt can waste storage space, interfere with airflow in storage and promote the development of certain storage diseases. The removal of excessive amounts of dirt and foreign material, such as weeds, is essential to maximize the storability of the crop.

Post-harvest handling and storage

Potatoes benefit from a period of curing before long-term, low temperature storage. Curing allows the natural process of wound healing to occur, which helps prevent storage disease development and moisture loss.

Harvested potatoes are cured by maintaining the storage temperature (with ventilation) at 15 to 20°C (59 to 68°F) and a relative humidity greater than 80 per cent for about 2 to 3 weeks. Following curing, storage temperatures should be lowered by no more than 2°C (35°F) per day until the desired long-term storage temperature is reached.

Storage requirements for potatoes vary considerably depending on variety, intended markets and condition of the potatoes. In general, potatoes destined for the table or fresh market should be stored at 6 to 8°C (43 to 46°F) to slow sprouting and respiration, and also to prevent low temperature conversion of starch to sugar, which reduces quality. Maintain relative humidity at around 95 per cent.

Table potatoes should be graded (for quality and size) and washed before sale. It is critical to disinfect the wash water regularly to minimize spread of disease.

Packaging will depend on the marketing channel used. Consider the potential for greening, moisture loss and other physiological changes that can reduce overall tuber quality, both after packaging and in retail settings.

Table potatoes should be marketed as quickly as possible once they are removed from long-term storage as quality will decrease rapidly at higher temperatures.

Radishes

Varieties/cultivars

Radishes are mainly round-shaped with red skins and white flesh. Other shapes (cylindrical) and colours (yellow, pink, white) are also available.

A variety of radish root colours and shapes are available

Climate and soil requirements

Radish is a fast-maturing, cool-season crop. Radishes grow best at temperatures between 16 and 18°C (60 and 65°F), with a minimum temperature requirement of 4°C (40°F) and a maximum of 24°C (75°F). Root quality decreases rapidly with hot conditions and insufficient moisture. Radishes grow best on soils that have excellent moisture availability and are not prone to drought or overheating.

Planting

Radishes are grown directly from seed. Due to their low temperature tolerance, they can be seeded very early in the spring. Continue planting at 1- to 2-week intervals until mid-August or early September to assure continued supply.

Radishes should be seeded 1 cm (0.5 in.) deep. Plant rows 20 to 30 cm (8 to 12 in.) apart with plants spaced at 40 to 45/m (12 to 15/ft.). Machine-harvested crops can be planted with rows 10 to 15 cm (4 to 6 in.) apart. Use 11 to 17 kg/ha (10 to 15 lb./ac.) of seed for regular spacing, and double that rate for the spacing required for machine harvest.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. In general, broadcast and incorporate the following:

- 22 to 50 kg N/ha (20 to 45 lb. N/ac.)
- 116 to 160 kg P/ha (105 to 145 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

Reduce the rates of phosphorus and potassium to one-fifth and one-half, respectively, when side-banding fertilizers.

Irrigation

Radishes are very shallow-rooted, and as such, they cannot be allowed to dry out. Moisture is most critical during root fill. Moisture deficiency will result in woody, bitter, poor quality radishes, and deformed roots and reduced yields.

Insect pest management

Flea beetles (various *Phyllotreta* species)

Description/life cycle

There is only a single flea beetle generation per year. Overwintering adults emerge early in the growing season and begin to feed on host crops. Eggs are laid in the soil near the roots of host plants, typically from late May until early July.

Flea beetle larvae feed on the roots of host plants, although they seldom cause economic damage. Adults emerge from late July and feed on whatever cruciferous hosts are available. In years when canola is swathed early, tremendous populations of flea beetles can migrate into adjacent vegetable fields.

Damage/symptoms

Feeding by overwintering adults can cause significant damage to early planted crops. Flea beetles cause characteristic “shot hole” damage to the cotyledons and leaves. Larval feeding on radish and rutabaga can have a significant effect on the marketability of those crops, and this damage may be masked by or confused with feeding damage by cabbage maggot. Damage can be a result of direct feeding or reduced vigour.

Control/management

Visual monitoring of populations can indicate if control measures are necessary.

The in-furrow or at-planting treatments required to protect rutabaga and radish from root maggot damage may also provide protection from flea beetles.

Late summer feeding is often most severe, notably following an early canola harvest. Management of these late season infestations is best achieved with foliar insecticides. Pay attention to pre-harvest intervals for these late season applications.

The use of transplants (in appropriate crops) can minimize the effect on early plantings as the transplants are more tolerant of some damage than a newly emerged crop.

Root maggots (*Delia radicum*, other *Delia* species)

Description/life cycle

Populations of root maggot are everywhere on the Prairies owing to the high acreages of canola, which serves as another host for this pest. Pupae overwinter and adults emerge as flies early in the spring. Emergence of the adults tends to correspond with the bloom of Saskatoon berry bushes.

Eggs are laid on the soil near the host plant. The creamy white, 1-cm (0.5-in.) long maggot larvae feed on the fine root hairs of the plant and later burrow into the taproot below the ground.

After 3 to 4 weeks, the maggots turn into rusty brown pupae that look like grains of brown rice.

After about 4 weeks, the adult flies emerge from the pupae. They mate, and the cycle repeats. There may be up to three generations per year.

Damage/symptoms
Root maggot larvae feeding on plant roots causes the primary damage. In crops like radish, rutabaga and turnip, the maggots attack the marketable root, resulting in scars on the outer root surface. These scars often render the produce unmarketable.

Internal feeding (tunnelling) may result in storage and marketing issues. In crops like cabbage, cauliflower and broccoli, damage to the root system may cause stunting of young plants. Large plants may have reduced growth, yield or lower quality.

Control/management
Monitor adult flies with yellow pan traps or yellow sticky traps. Check for eggs by scraping some soil away from the base of the plants. Dissolve the soil sample in water, and look for the small white eggs floating on the surface of the water.

Time the application of chemical control agents to coincide with the arrival of the pest problem. Chemical control is achievable with in-furrow and post-planting drench treatments. For longer season crops, such as rutabaga and turnip, multiple treatments of insecticide will be required. Pay very close attention to the pre-harvest intervals listed on the chemical product label.

Fine fencing may provide additional control near the fencing, but at greater distances out, insecticide treatment is likely to be necessary. Crop covers may protect the crop from egg laying adults. No biological control options are currently available.

Disease management

Blackleg (*Phoma lingam*)

Description/disease cycle
Blackleg infects seedlings causing lesions in which pycnidia (fruiting bodies) are formed. Conidia (spores) are exuded from these pycnidia in long, pink to lilac chains. Then, the spores may be splashed onto nearby cruciferous plants. Ascospores (a form of spore) may become air-borne and be transported great distances.

The fungal pathogen may survive for at least 4 years in seed and can survive for 3 years in crop residues.

Symptoms/damage
Seedlings that become infected may be killed. Other, older plants may only exhibit dead, withered cotyledons or bluish lesions on the stems at the cotyledon scar. As the disease develops, elongated, light brown sunken areas with a purplish or black margin may form near the soil line. As the lesions gradually extend upwards and downwards below the soil line, the stem becomes girdled and blackened. Many small, black pycnidia form in these lesions.

On rutabagas and turnips, cankers may form on the fleshy taproot. A dry rot of the taproot may develop. The neck and shoulder areas develop large brown lesions with black margins, and numerous pycnidia can be formed. The decay can extend deep into the fleshy root. After blackleg develops, secondary decay organisms often exploit the damage caused.

Circular, light brown to grey spots form on the leaves. Pink tendrils may form in large numbers in the lesions.

Control/management
Maintain a 4-year crop rotation. Rogue (cull) diseased plants from seedbeds, and incorporate crop residue. Ensure fields are well drained. Keep fields free of cruciferous weeds. Avoid cultivating when wet. Do not grow crops downwind of fields where canola was grown the previous year because surface water, wind and rain may spread the fungus from one field to another.

Seed may be hot-water-treated to remove inoculum. Do not dip transplants or spray with water before planting.

Cultivars vary in susceptibility, with some turnip, rutabaga and radish cultivars showing good tolerance to almost immunity.

Scab (*Streptomyces scabies*)

Description/disease cycle
This disease occurs on the fleshy roots or enlarged hypocotyls of radish, rutabaga and turnip. See Common Scab in the Potatoes section for a detailed description of this pathogen's life cycle.

Symptoms/damage
The initial symptoms include the development of small, scale-like spots on the roots, about 1 mm (0.03 in.) wide, with individual spots reaching 1 to 1.5 cm (0.4 to 0.6 in.). Spots have raised edges, with the centres sunken and pitted.

On rutabagas and turnips, lesions are circular, often reaching 1 to 1.5 cm (0.4 to 0.6 in.) and are scattered over the root surface. Affected tissues may have a tan coloured, superficial or raised layer, or tissues may become pitted and dark following infection by secondary organisms.

The superficial scab lesions do not decrease yields, but a single lesion renders the root virtually unsalable in some markets.

Control/management
Scab development in radishes and other root crops tends to be more severe after a potato crop. While the scab pathogen will persist in the soil, rotations away from susceptible crops can slow disease development. Growing non-host cereal or green manure crops can be beneficial.

Maintain adequate soil moisture levels throughout the growing season. Avoid excessive irrigation over many seasons.

Few cultivars are resistant to scab.

Weed management

As much as possible, control weeds before planting the radish crop. Plant into a clean seedbed. Shallow cultivation may be necessary. Relatively few herbicides are registered for use in radish.

Harvesting

Radishes mature quickly and should be harvested at the correct time. Over-mature radishes tend to be tough, stringy or woody. Radishes may be harvested by hand or mechanically.

Radishes should be uniformly shaped, well-coloured, smooth and free from cuts, abrasions, deformities or other damage or debris.

Radishes are sold either with tops in bunches or topped. Bunch radishes should have well formed, green leaves free from insect damage and/or discolouration.

Post-harvest handling and storage

Radishes should be cooled as quickly as possible to prolong the post-harvest lifespan. Wash them in chlorinated water, and then store them at 0°C (32°F) and humidity greater than 95 per cent. Bunch radishes have a storage life of 10 to 14 days. Topped radishes may store for as long as 4 weeks.

Rutabagas (Swede turnips), turnips

Varieties/cultivars

Rutabagas and turnips are related (both are *Brassica* crops). Rutabagas have large, usually yellow-fleshed storage roots. Turnips have small, white-fleshed roots, often with a purple surface on the top-half of the root.

Climate and soil requirements

Rutabagas and turnips are cool-season crops and have similar growing season requirements as those of cabbage, broccoli, etc. Rutabagas grow optimally at temperatures between 16 and 18°C (60 and 65°F) but will grow when temperatures are above 4°C (40°F) and below 24°C (75°F). Rutabagas and turnips can tolerate frost in both spring and fall. Turnips are more heat-tolerant than rutabagas.

Rutabagas and turnips grow best on slightly heavier soils, such as clay or clay loam soils, as these soils offer good moisture- and nutrient-holding capacity, combined with decent drainage. Heavy clay soils should be avoided. Soils should be well drained with a neutral pH.

Planting

Seed rutabagas for early market use as soon as possible in the spring, once soil temperatures climb above 5°C (41°F) and when the risk of heavy frosts is reduced. Rutabagas destined for storage can be planted in mid-June so that harvest quality (size) and timing are achieved.

Place seeds 1 to 2 cm (0.5 to 1 in.) deep. Rows are typically spaced 60 to 90 cm (24 to 36 in.) apart. Final in-row spacing should be 13 to 15 cm (5 to 6 in.). Closer row spacing may be more productive, but may result in smaller average root size, and the tops may bind at harvest time. Depending on the type of seeding equipment available, 0.5 to 2.27 kg/ha (0.5 to 2 lb./ac.) of seed will be required.

Seeding requirements for turnips are similar to those for rutabagas. Turnips are not commonly stored for long periods, so the planting time is not usually based on that consideration.

Fertilizer

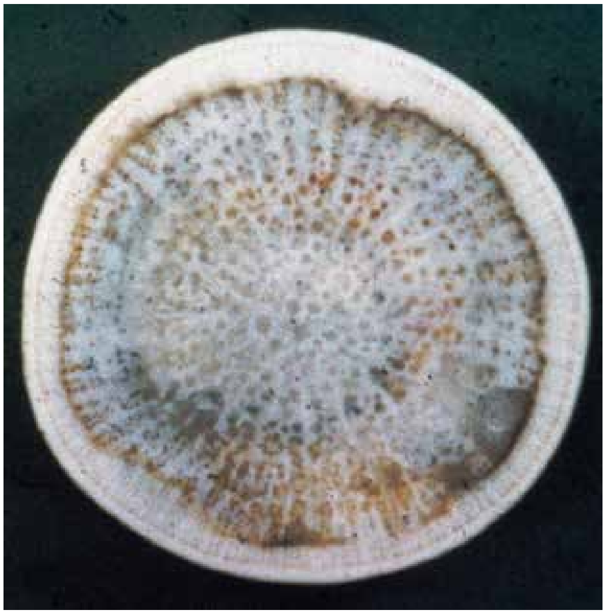
ALWAYS base fertilizer applications on the results of annual soil tests. In general, apply at least the following:

- 33 kg N/ha (30 lb. N/ac.)
- 77 to 116 kg P/ha (70 to 105 lb. P/ac.)
- 50 to 143 kg K/ha (45 to 130 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

Consider the amount of fertility in the soil. Excess nitrogen levels can cause excessively rapid growth, which leads to root cracking.

Boron deficiency has been seen in certain rutabaga crops in some areas of the Prairies. Boron deficiency causes water core or brown heart, which may occur in the field or during storage. Boron deficiency is likely to occur in soils where pH is greater than 6.5 and is more likely to occur in dry years.

Soil testing for boron deficiency is ineffective; visual symptoms and tissue testing are better tools.



Boron deficiency in rutabaga resulting in water core
Photo: R.J. Howard, Potato Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Boron may be added to granular fertilizer blends before planting or applied as a foliar spray when roots are about 2 cm (1 in.) in diameter. This foliar application may be repeated at 10- to 14-day intervals if necessary.

Boron is only required in small quantities, and an overdose may be toxic to both the current crop and to crops following rutabagas. Take care in its use. Do not plant legumes or cucumbers the year following boron application.

Irrigation

Rutabagas and turnips require about 25 mm (1 in.) of moisture every 10 to 14 days. Moisture is most important during root filling and expansion.

Insect pest management

The most common insect pests that affect rutabagas and turnips are cabbage maggots and flea beetles. See Insect Pest Management in the Radishes section for detailed information. Given the longer duration of the growing season for rutabagas and turnips, compared to radishes, multiple applications of pesticides will be required to keep the maggots under control.

Disease management

Diseases that affect rutabagas and turnips are similar to those that affect radishes. For more information, see Disease Management in the Radishes section. Some physiological disorders may occur in rutabagas under certain environmental and soil conditions.

Sclerotinia on rutabaga (*Sclerotinia sclerotiorum*)

Description/disease cycle

Sclerotinia is the same disease that is observed on carrots. See Sclerotinia Rot in the Carrots section for a detailed description.

Damage/symptoms

This disease is primarily a storage disease. After the initial infection occurs, a slightly pinkish colour may be present on the margin of the lesion, while the inner portion of the lesion is pale brown and water-soaked. The typical white, cottony mycelium (vegetative part of the fungus) and sclerotia (mass of hardened fungal mycelium) later appear on infected tissues as the disease develops.

Control/management

Turnips and rutabaga roots should be free of soil, as washing will reduce the likelihood of disease development. See Sclerotinia Rot in the Carrots section for general management practices.

Weed management

Relatively few herbicides are registered for use in rutabagas and turnips. Members of the mustard family such as stinkweed, wild mustard, shepherd's purse and volunteer canola cannot be chemically controlled in rutabagas and turnips. As much as possible, control weeds before planting.

The ability of rutabagas and turnips to compete with weeds is reasonably good after the first 6 weeks of the growing season.

2,4-D damage

Rutabagas are sensitive to 2,4-D. Although symptoms of 2,4-D spray drift may not show on the top growth, the root development can be affected. Be sure to place rutabaga fields away from grain crops that will be sprayed with 2,4-D.

Harvesting

Rutabagas and turnips should be harvested when they are fully mature because immature roots will have poor taste, reduced sugar development and limited storage potential. Sweetness may be enhanced if the roots are harvested after several fall frosts. Harvest should take place in cool weather to reduce post-harvest cooling requirements and increase post-harvest lifespan.

Rutabagas should be smooth and free from damage; they should also have a well formed, purple-topped taproot and few secondary roots. Turnips should be smooth, firm and free from cracks, woodiness or other damage. Some trimming of root maggot damage is permitted.

Post-harvest handling and storage

Both rutabagas and turnips should be cooled as quickly as possible after harvest to prolong storage lifespan. Careful handling to avoid bruising will result in longer storage life. Rutabagas and turnips should be washed in clean, disinfected water and then rinsed and dried as quickly as possible.

Roots may then be trimmed, removing tops. All tops must be removed before storage. Avoid trimming into the crown as much as possible so as not to open a pathway to infection of the root. Side rootlets and the taproot below the main, enlarged area of the root should also be removed.

Rutabagas and turnips store best at a temperature of 0°C (32°F) and relative humidity of 95 per cent or greater. Adequate ventilation is also required. Rutabagas will store for 6 to 7 months in good storage conditions, whereas turnips will store for 4 to 5 months. Both crops can be stored in bulk or in tote bins.

Before marketing, rutabagas are usually trimmed to remove any sign of maggot damage and then waxed. Waxing can help keep roots clean and can offer some protection from moisture loss and post-harvest disease development. Roots are dipped in a special hot wax for one second and then held at lower temperatures as much as possible.

Turnips may be sold in bunches with tops, in bunches with trimmed tops or as topped turnips. Topped turnips may or may not be waxed.

Bulb vegetables

Garlic

Varieties/cultivars

Softneck garlic (*Allium sativum* var. *sativum*) is characterized by many small cloves that form several layers around the central core. There is no central scape (flower stalk).

Stiffneck garlic (*Allium sativum* var. *ophioscorodon*) forms a stiff, central scape (stem) where flowers and small bulbils (bulb-like features) develop. Stiffneck garlic may show more robust growth than softneck types, especially if fall planted; however, this difference may be negligible.

Climate and soil requirements

Garlic will grow in most areas of the Canadian Prairies, but some cultivars are less hardy than others. Garlic is a cool-season, moisture-loving crop. High temperatures inhibit bulb formation and cause plants to stop growth early.

Garlic can be grown on many different soil types providing the soils are well drained and fertile and have sufficient organic matter to provide good nutrient- and moisture-holding capacity. Heavy soils may not be suitable as they can make bulb cleaning difficult and may restrict normal bulb development, particularly in dry years.

Planting

Garlic is typically established by planting cloves saved from the previous year's crop. However, a number of diseases and pest problems (e.g. nematodes) are carried over from year to year and spread from field to field in planting material, so it is important to plant only clean, disease-free material. As there is no formalized certification program for seed garlic, the responsibility for assessing the disease status of planting material falls to the grower.

Some growers are attempting to reduce the risk of introducing soil-borne diseases and pests by using bulbils to establish their garlic crops. While this approach is effective against some diseases, it does not protect against viral diseases. Additionally, using bulbils to establish the crop delays the harvest by a full year.

While preparing the cloves for planting, discard any diseased material. Carefully crack (break apart the head) just before planting. If the cracking process causes physical damage, the cloves will likely rot before emerging. Cracking is best done by hand, although home-built machines are common in larger operations. Small cloves should be graded out as they are useless to plant. Where penicillium mould is an issue, consider treating the cloves just before planting.

Garlic may be planted either in the spring or fall. Fall planting allows the crop to start growing before the fields are usually accessible in the spring, which reduces spring planting delays. Fall planting also allows the crop to have effectively matured before the onset of hot weather.

Spring-planted garlic will likely have reduced bulb sizes and yields, particularly in a hot year. If spring planting is selected, plant previously chilled cloves as early as fields can be accessed.

Fall-planted bulbs do not require a cold treatment. However, they will require some protection (e.g. straw mulch) to reduce winter injury if there is typically insufficient snowfall in the area. Experience has shown that garlic can be planted anytime in the fall.

Garlic cloves should be planted in rows 20 cm (8 in.) apart, although rows can be spaced as much as 60 cm (24 in.) apart, depending on the equipment. Space plants 7 to 12 cm (3 to 5 in.) apart within the row, increasing the space between plants in lighter soils. Cloves should be planted to allow for 3 to 5 cm (1 to 2 in.) between the soil surface and the top of the clove.

Depending on the plant, row spacing and average clove size, 900 to 2,240 kg/ha (800 to 2,000 lb./ac.) of garlic clove will be required to plant the garlic crop.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Most of the required fertilizer should be applied before planting. Generally, an annual application of the following will be required:

- 110 kg N/ha (100 lb. N/ac.)
- 116 to 160 kg P/ha (105 to 145 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If side-banding phosphorus or potassium, reduce rates to one-fifth and one-half, respectively.

Apply the required nitrogen in split applications, with half applied at planting or as soon as plants begin to grow in the spring and the remainder in 2 to 3 side-dress applications about every 3 weeks. Fertilizer applications should stop 4 to 6 weeks before harvest to promote maturity.

Irrigation

Like onion, garlic is shallow-rooted and intolerant of moisture stress. The soil profile should not be allowed to reach the point where plants are unable to access the moisture.

In most soils, about 25 mm (1 in.) of water will be required per week (including precipitation). An additional 25 mm (1 in.) may be required on very sandy soils. Reduce moisture application as the crop starts to mature so as to hasten drying down and improve storage quality.

Insect pest management

Insect pests of garlic are the same as for onions. See Insect Pest Management in the Onions section for more information.

Disease management

Diseases common in garlic are the same as those in onions. See Disease Management in the Onions section for more information.

Weed management

Due to its slow growth and limited leaf area, garlic does not compete well with weeds at any growth stage. Control perennial weeds before planting, and control annual weeds in crop as well as possible. Use registered herbicides if necessary.

Other requirements

Winter protection

In areas where snowfall is typically less than 15 cm (6 in.), some winter protection will be required for fall-planted garlic. The application of clean (free from weeds, etc.) wheat straw to a thickness of up to 15 cm (6 in.) over the crop should provide sufficient protection. Straw will need to be removed in spring as soon as possible; otherwise, emergence of the garlic crop will be delayed.

Flower stem removal

Stiffneck garlic produces a flower stem (scape). Remove these stems by cutting or snapping them off shortly after they first appear to encourage bulb filling and development. Young scapes are commonly marketed as garlic greens.

Harvesting

Garlic should be dug once the lower third of the tops have died back. Garlic may be harvested by hand or undercut. Delayed harvests can result in reduced quality.

Post-harvest handling and storage

Similar to dry bulb onions, freshly harvested garlic should be cured before storage. If suitable conditions exist, curing can occur in the field or indoors. Bulbs are cured for 20 days at 20°C (68°F) with good ventilation. Roots and stems should be removed after curing. Brush the bulbs to remove dirt and other loose debris.

Bulbs should be stored at 0°C (32°F) to reduce weight loss, sprouting and decay. Maintain relative humidity between 60 and 70 per cent with good air movement within storage. With good storage conditions, garlic may be stored for 5 to 8 months.

Many producers retain a portion of the crop as seed for future crops. Seed garlic should be held at 6 to 10°C (43 to 50°F) for 2 to 3 weeks before planting.

Onions

Varieties/cultivars

Dry bulb onions, also referred to as cooking or storage onions, are the most common type of onion. They are available in a wide range of sizes, shapes, colours and sweetness/pungency levels including yellow, white, red, Spanish, etc.

Dry onions are grown for their bulbs and are typically geared toward long-term storage. In general terms, storability is longest in yellow onions, followed by reds, whites and Spanish onions. This characteristic relates to the amount of pungency of the onions, with the most pungent storing the longest.

Bunching onions, scallions, green onions and shallots are grown at very tight plant densities and are harvested before any bulb formation. These onion types are used fresh, with a short post-harvest lifespan.

Onion sets are produced when different types of onions are grown close together, producing small bulbs. These sets are used to shorten maturity times for onions used in non-commercial settings.

Climate and soil requirements

Green onions and shallots have a relatively short growing season. Dry bulb onions require a fairly long growing season to mature (120+ days). Sweet or Spanish onions require an even longer season than other dry bulb onions.

Onions are fairly cold-tolerant crops and can be planted early. Onions (and other bulb vegetables) grow best between 13 and 24°C (55 and 75°F), but can tolerate temperatures as low as 7°C (45°F) and up to 29°C (85°F).

Onions grow best on silty-sand or clay loam soils, but they can be grown on all well drained soils.

Planting

Onions can be started directly from seed, from sets or from transplants. Spanish and other late maturing bulb onions must be started from transplants to give them time to mature within a short growing season.

Onions will germinate at cool temperatures and can be planted when the soil temperature reaches 5°C (41°F). Seeds are planted 1 to 2 cm (0.5 to 0.75 in.) deep. Seeding should take place as early as possible in the spring, provided soil temperatures are suitable. Yields and crop quality will be reduced if the seeding date is pushed back. Fall seeding of some types of onion is also possible.

Dry bulb onions may be planted in a range of row configurations, depending on the seeding and harvesting equipment. Producers can plant multiple rows in beds or a series of single rows. Rows range from 25 to 60 cm (10 to 24 in.) apart, depending on onion type and equipment available. For multiple-row beds, use narrower between-row spacing.

Bed configurations can include 3 to 5 rows, with beds ranging from 90 to 135 cm (36 to 54 in.) across. Increased plant density may increase overall yields, but will make it difficult to control weeds by tillage and will reduce bulb size.

Bunching and pickling onions should be planted as early as possible in the spring. High populations of evenly spaced plants result in good yields of uniform onions. Seed requirements range from 48 to 73 kg/ha (44 to 66 lb./ac.) but may vary depending on seed size and the row spacing used. Bunching onions should be planted sequentially because they are not typically stored for more than a few days.

Transplants are recommended when growing dry bulb onions in more northern regions and when growing Spanish onions in most areas. To produce the transplants, seeds should be started in flats about 6 to 8 weeks before planting. Seedlings should be field set as early as possible (typically early May). Well hardened onion transplants can withstand frost or light freezing without injury. Space the transplants 10 to 15 cm (4 to 6 in.) apart in rows that are 36 to 60 cm (14 to 24 in.) apart.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally, for dry onions, broadcast and incorporate the following before seeding:

- 110 kg N/ha (100 lb. N/ac.)
- 116 to 160 kg P/ha (105 to 145 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If side-banding phosphorus or potassium, reduce rates to one-fifth and one-half, respectively.

Over-application or late season application of N will delay maturity and limit the storage potential of the crop. Some of the nitrogen may be applied as a side-dress application in mid-July.

For pickling onions, apply only 22 to 50 kg N/ha (20 to 45 lb. N/ac.) with the remaining nutrients the same as for dry onions.

Irrigation

The coarse, shallow root system characteristic of all members of the onion family renders them susceptible to moisture stress. Onions need to be watered frequently.

Onions may use 4 to 5 mm (0.16 to 0.20 in.) of water per day during peak use periods and from 350 to 500 mm (14 to 20 in.) over the growing season, including precipitation.

Apply 25 mm (1 in.) of water per week (including precipitation). The critical moisture period is up to and including bulb formation and enlargement.

Insect pest management

Onion maggot (*Delia antiqua*)

Life stages of onion maggot beginning in left corner (counterclockwise): eggs, pupa, larva and adult flies
Photo: B. A. Nault and J. Ogrodnick, Cornell University

Onion maggot damaged bulbs
Photo: Brian A. Nault and Joe Ogrodnick, Cornell University

Description/life cycle

Adult onion maggots are similar in appearance to a house fly. Eggs are white and laid in batches at the base of the onion plants and hatch within a few days. Larvae are pale maggots that move toward the onion root to feed. Mature larvae leave the onion plant to pupate in the soil. Pupae are 5 to 7 mm (0.2 to 0.28 in.) long and brown, similar in colour and shape to a grain of rice.

On the Prairies, there are typically two onion maggot generations per year. A third generation is possible if an onion cull pile is nearby, as the heat generated from the cull pile will be sufficient to allow the life cycle to be completed a third time. Onion maggots overwinter in the pupal stage.

Damage/symptoms

Larvae feeding on the roots and developing bulbs can cause significant crop losses. Damage can include wilting and the death of younger plants, reduced vigour in older plants and damage to the base of the bulb, rendering it unmarketable.

Control/management

Typically, the first generation does the most damage in commercial plantings. In the Prairie provinces, economic threshold populations are typically not reached as long as good crop rotations are in place. If rotations are too tight in time or space, then maggot damage can reach economic threshold levels. Sanitation and rotation are critical in helping minimize pest attacks, although the adult flies are highly mobile.

Monitoring the movement and numbers of adult flies is typically achieved with yellow sticky traps. Chemical control is most effective using granular products applied at the time of seeding. Further foliar applications can be made to try to control adult flies, but these applications may be limited in their ability to reduce bulb damage by maggots.

Thrips (*Thrips tabaci*)

Onion thrips at different life stages
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle

Adult thrips are very small (1 to 1.2 mm; 0.04 to 0.05 in. in length), cigar-shaped, pale yellow to brown insects with four narrow, fringed wings. Nymphs (larvae) resemble wingless adults, only smaller. Both adults and nymphs move readily about the plant, preferring to feed in the tight spaces at the base of leaves.

Thrips tend to hide or drop off the plant if disturbed. Separating leaves is often necessary to detect their presence. Tapping a plant over a piece of paper can allow the thrips to be counted.

Adults often overwinter in crop residue left in fields or in alfalfa or winter wheat. There can be several generations per year.

Damage/symptoms

Thrips feed by piercing the plant and sucking up plant juices. This feeding causes small, silvery streaks to form on the leaves. As these areas grow, they become larger, whitish patches. Heavy thrips feeding may cause earlier ripening, smaller bulbs or even plant death in heavy infestations in hot, dry summers.

Damage to onion leaves caused by onion thrips
Photo: Courtesy S. K. Mohan; Reproduced, by permission, from Schwartz, H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Control/management
Sanitation and crop rotation are critical in the management of thrips. Monitor the pests by using sticky traps or visual scouting. Foliar applications of insecticides are useful when economic thresholds are reached. However, thrips are renowned for the rapidity with which their populations develop resistance to pesticides. Carefully rotate control methods and products.

Disease management

Aster yellows (aster yellows phytoplasma)

Onion umbel deformation caused by a phytoplasma; note distorted flowers, long pedicels and bulblet formation
Photo: Courtesy H. F. Schwartz; Reproduced, by permission, from Schwartz, H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Aster yellows affects a wide range of host plants, including cereals, oilseeds, numerous vegetables and ornamentals.

Relative to carrots and lettuce, onions are generally not affected as severely.

Damage/symptoms
Initial symptoms may include a slight yellowing near the base of the newest leaves that then spreads to the top. Leaves may appear flattened and have yellowish-green streaks. Plants are usually stunted, and yield as well as bulb size are reduced.

Control/management
Controlling the insect vector that carries aster yellows is the only way to manage this disease. See Aster Yellows and Aster Leafhopper in the Carrots section for control methods using insecticides.

Botrytis diseases:

Brown stain rot, soil-line rot (*Botrytis cinerea*)

Brown stain of onion bulbs, caused by *Botrytis cinerea*
Photo: Courtesy H. F. Schwartz; Reproduced, by permission, from Schwartz, H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Botrytis cinerea is a common fungal pathogen found on a wide range of hosts. It has the potential to cause damage to injured or wounded onions. The disease can occur throughout the season.

This pathogen overwinters on crop debris (both in onion crops and a wide range of other hosts) and can move into fields by spores produced on other crops.

Brown stain rot is a superficial discolouration of onion bulbs that can lead to the downgrading of onion quality due to the appearance of the bulb, not its food quality. This disease is the result of infections that have been stopped and are unable to cause further damage. The brown stain symptom can be a problem depending on the projected end use of the onions.

Soil-line rot is observed when infections occur at the soil line, typically associated with wounding or injury.

Damage/symptoms
Symptoms of brown stain look like coffee stains. A dark brown discolouration appears on the outer scales of the onion, either from individual lesions or a general discolouration of the entire surface of the bulb.

Soil-line rot, as the name suggests, occurs near the shoulders of the onion. It can resemble neck rot. Thick, grey mycelium and spores are produced, and the onion may rot, occasionally breaking down entirely and remaining in the soil. Hardened, resting structures (sclerotia) are produced and can remain in the soil.

Control/management
Crop rotation to non-onion crops as well as the elimination of inoculum sources, such as cull piles, can help slow the rate of disease inoculum buildup. Applications of fungicides for the control of botrytis leaf blight may also reduce the severity of this disease.

Botrytis leaf blight (*Botrytis squamosa*)

Description/disease cycle
Botrytis leaf blight is generally a problem anywhere onions are grown. When disease conditions are suitable, the disease can do extensive damage to onion and other bulb vegetable yields if left unmanaged.

Spores produced on nearby onion crop debris or sclerotia in the soil are carried in the air to susceptible plant tissue. Infection can occur directly through the leaf surface, with as little as 6 hours of leaf wetness necessary for infection. As the period of leaf wetness increases, the number of lesions also tends to increase. Disease development is favoured by temperatures between 12 and 24°C (54 and 75°F), which are typical of early spring weather on the Prairies.

The disease tends to be more of a problem in densely planted crops since air movement is limited. Rapid senescence of leaves can reduce the efficacy of sprout inhibitors, reducing storage lifespan of the crop.

This disease can continue to cycle throughout the year. With more leaf blighting and senescing of leaves, more conidia (asexually produced spores) are produced, which can continue disease development on both infected and healthy plants.

Damage/symptoms
Symptoms of botrytis leaf blight can initially be confused with other diseases or injury. Close examination of early infections will reveal round to oval, white to grey leaf spots that are 1 to 3 mm (0.04 to 0.12 in.) in size. These lesions may tear.

Newly formed lesions appear silvery as the leaf epidermis is detached from the leaf surface. Light green, 1- to 1.5-mm (0.04- to 0.06-in.) wide halos occur around the lesions. Lesions may increase to 1 cm (0.4 in.) in size and coalesce into larger necrotic areas, giving the leaves a bleached appearance. Eventually, leaves collapse completely and leaf death occurs.

The disease causes reduced onion bulb sizes, which are less marketable, resulting in yield reductions.

Control/management
When planting, position plants in single rows spaced at least 30 cm (12 in.) apart to improve air circulation. Irrigate early in the day to increase the rate of leaf drying.

Incorporate residues into the soil after harvest. Do not leave culled onions near the field, and eliminate cull piles. When sclerotia become established in the soil, rotate to non-host crops, such as carrots, lettuce, celery, etc.

Fungicides are typically necessary to manage this disease, with a number of registered products available. Disease forecasting models have been created to increase the accuracy of fungicide application timing.

Resistant onion cultivars are not known, but other species in the same genus as onions (*Allium*) appear to show promise for breeding resistance into onions. For example, chives are reported to be immune to botrytis leaf blight.

Botrytis leaf blight lesions on onion
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Neck rot (*Botrytis allii*)

Watery decay of onion neck, indicative of neck rot infection
Photo: D. Ormrod and W.R. Jarvis, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Cross-section of neck rot infected onion
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle

Neck rot infection occurs in the field, but the effect is primarily found in the storage phase of onion crops. This disease is considered to be the most important issue facing commercial onion producers in most Prairie provinces.

Improvements to harvesting and storage methods have reduced the effect of this disease in some onion growing areas. Currently on the Prairies, few producers have the artificial drying facilities that can have a significant effect on reducing disease levels.

Producers who do not have drying facilities must rely on natural processes of drying and may still experience problems, particularly when rains occur just before or at the time of onion pulling. Garlic, leeks and shallots are also susceptible to neck rot.

The fungus can be disseminated on seed and in sets of onions and shallots. However, most seed is treated with fungicides that also provide a measure of control of the neck rot pathogen. When seed is stored at a low enough temperature, it is possible for the fungus to survive for as long as 3 years.

Soil-borne and residue-borne sclerotia are prime sources of the pathogen and have been reported to survive for 2 years in buried debris. Sclerotia can produce conidia or may germinate directly as mycelium.

Usually, *Botrytis allii* infects the crop through leaves and then begins to sporulate (form spores) as the tissue senesces (ages); at which point, foliar symptoms appear. When the foliage is topped just before harvest, the wounds created provide entry points for the fungus. While the neck region retains moisture, the pathogen can grow down into the bulb where rotting of the scales can begin.

Damage/symptoms

This pathogen is commonly found on bulbs in storage. The pathogen may spread from the neck into the bulb. Fungal growth only becomes apparent after several weeks in storage.

Typically, a watery decay begins in the neck area. Initially, the tissue of the scales softens, becoming grey, water-soaked and translucent. White to grey mycelium develops between the scales, and black sclerotia and mould may form on the outer and inner scales on the bulb shoulder. The black sclerotia are about 5 mm (0.2 in.) in diameter and develop on bulb shoulders. Decayed tissues often appear depressed and lack the firmness of a healthy onion.

Storage onion infections can be initiated from seed-borne infections or from infection of the necks during curing or as bulbs are harvested and placed into storage.

While typically the necks of the bulbs are attacked, this pathogen can affect any part of the bulb. The basal portion of the bulb may be infected first, with the pathogen developing upwards to the neck region.

If left untouched, entire bulbs can become mummified and contain large numbers of sclerotia.

Control/management

The elimination of onion cull piles is critical to avoid the creation of a supply of spores that can infect new tissues. Destroy any volunteer onions. Avoid planting into onion debris. Encourage the breakdown of debris by incorporation. Rotating to carrots, beets, corn and other field crops can help reduce the number of sclerotia that survive in the soil.

Grow resistant early maturing, tight-necked varieties. Plant crops as early as possible and at appropriate crop densities. Restrict soil moisture and nitrogen early in August to encourage tops to die down and natural curing/drying to commence. Do not lift onions until two-thirds of the tops are down. Undercutting will accelerate this dying-down process. Do not top poorly cured bulbs.

The use of registered fungicides may reduce the incidence of this disease in harvested onions, but an integrated approach will likely yield the best results.

Heat cure onions in storage, if possible. Lower relative humidity to 60 per cent, until the onion skins are a rich golden brown. Once onions are cured, storage temperatures should be just above 0°C (32°F) with a relative humidity of 65 to 75 per cent.

Downy mildew (*Peronospora destructor*)

Extensive downy mildew dieback

Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle

Downy mildew is a destructive disease of onion that occurs occasionally on the Prairies. This pathogen is in the same group of pathogens as potato late blight (*Phytophthora infestans*) and can have similar explosive outbreaks under suitable conditions.

This disease affects yields through the destruction of foliage, decreasing yields and bulb quality by reducing bulb size. Infected bulbs may also have softer necks that are more difficult to cure and store.

Downy mildew overwinters in infected bulbs, sets, debris, culls, volunteers or other hosts, producing spores that invade new growth in the spring. Seeds are not likely inoculum sources.

Prolonged periods of free moisture on the leaf surface are necessary for infection to occur, although as little as 3 hours of leaf wetness can be sufficient. Cooler conditions (less than 22°C; 72°F) are required for disease epidemics to develop. Control can be difficult to achieve once the pathogen begins to spread.

Damage/symptoms
Downy mildew begins as small, irregularly shaped, chlorotic spots on leaves. These spots enlarge and coalesce, appearing slightly paler than surrounding healthy tissue. These lesions can affect large portions of each leaf and may range in size from 10 to 15 cm (4 to 6 in.) in length.

When spores are produced, the lesions appear fuzzy with a grey to purple discolouration. Leaf tips may be necrotic and bleached in appearance. Larger lesions can girdle leaves and cause them to collapse completely. In severe outbreaks, entire fields can be lost after only four or five cycles of the disease.

Stemphylium fungi may colonize infected areas, giving the lesions a dark brown colour.

Control/management
Rotations of 3 or 4 years to non-susceptible crops may help in areas where outbreaks have occurred in the past. Bury crop residue to speed up the breakdown process. Promptly destroy culled onions near a production field.

If possible, choose fields or areas within fields that have good air movement and drainage, as this approach will help promote the rapid drying of leaves. Consider orienting crop rows parallel to prevailing winds, again to speed up the drying of foliage. In irrigated fields, drip irrigation may be of value. If possible, avoid sprinkler irrigation.

The use of disease-free onion sets is crucial. There is some variation in the level of tolerance to downy mildew in common cultivars.

Fusarium basal plate rot (*Fusarium oxysporum* f. sp. *cepae*)

Mid-season foliar symptoms of fusarium basal rot of onion, caused by *Fusarium oxysporum* f. sp. *cepae.*
Photo: Courtesy H. F. Schwartz; Reproduced, by permission, from Schwartz, H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Fusarium basal plate rot can occur sporadically in onion and garlic production on the Prairies. Generally, the high soil temperature requirements for disease development make it an infrequent problem. This disease has been observed in Manitoba, though losses are rarely of economical concern.

Severe infection of fusarium basal plate rot
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Fusarium oxysporum f. sp. *cepae* is a soil-borne pathogen that can survive harsh conditions as hardened resting spores. This fungus has been spread to a number of growing areas by infected onion sets and garlic cloves.

Symptoms are rarely observed below 15°C (59°F), but as temperatures approach 30°C (86°F), disease development can occur. Onions of any age are susceptible, although onions that have been injured at the stem plate, either mechanically or by onion maggot, are more commonly affected.

The effects of basal plate rot can be masked by secondary decay organisms that exploit the damage and cause significant breakdown of the bulb. Wet weather close to harvest appears to promote disease development, especially in garlic crops. In storage, the spread of this disease between bulbs has not been reported as a problem.

Damage/symptoms
Yellowing, leaf necrosis and red-purple discolouration of the stems and bulbs are the first observed symptoms of this disease. The rotted area may appear soaked and light tan to brown. As the disease progresses, the infected base may develop into a soft rot, which extends into the scales and leads to collapse of the plant. Plants may appear symptomless at harvest, but can rot in storage.

If basal rot is suspected in plants that have no above ground symptoms, a bulb can be cut lengthwise from top to bottom. Discolouration of the basal plate in the outermost layer extending upward is suggestive of basal plate rot.

Control/management
There are limited options to manage this disease. Use resistant cultivars, if available. Plant disease-free transplants to reduce the risk of introducing basal rot disease.

Rotate crops for at least 4 years with non-susceptible plants. Well drained fields are less likely to have problems with this disease. Control onion maggot and avoid injury to bulbs during cultivation, harvesting and storage. Storing bulbs below 4°C (39°F) can reduce decay in storage.

Purple blotch (*Alternaria porri*)

Damage to onion seed stalks caused by purple blotch
Photo: Courtesy S. K. Mohan; Reproduced, by permission, from Schwartz, H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Purple blotch disease can infect both onion and garlic. It can reduce bulb size and quality significantly and has the potential to be quite destructive.

Conidia can form on lesions at relative humidity levels of 90 per cent or higher, and the fungus can grow between temperatures of 6 to 34°C (43 to 93°F).

Spores that land on susceptible tissues germinate and can penetrate stomates (tiny pores) or enter directly through the epidermis. Initial symptoms appear about 4 days after infection, and spores can be produced as soon as 5 days after infection. Cycles of infection can occur throughout the growing season if conditions are favourable for the disease.

Mycelium can overwinter on crop debris, and conidia can also be produced on the debris. Onion leaves become increasingly susceptible with age. Emerging leaves are more susceptible the closer they develop to bulb maturity. As a result, purple blotch can be very difficult to manage late in the season.

Young leaves of plants infested by onion thrips are more susceptible to infection by purple blotch.

Damage/symptoms
Initially, water-soaked lesions quickly develop white centres that enlarge to become concentric rings. The lesions take on a brown to purple discolouration, with a margin that appears purple to almost red. Chlorotic areas extend lengthwise along the leaf outside the lesion. *Stemphylium* fungi may colonize the lesions, giving them a dark brown to black colour.

Control/management
Select land that has good air and water drainage and that will allow a good flow of air through the crop. Apply irrigation in such a way as to enhance the drying of foliage. This approach might include watering in the late morning or early afternoon or through a drip irrigation system.

Destroy crop residues from infected crops. Grow onions in rotations with unrelated, non-host crops such as carrot, celery, lettuce or potato. Cull piles should not be near onion production fields.

Plant resistant or tolerant cultivars, if available. Sweet Spanish onions are reportedly very sensitive to purple blotch.

Protective fungicides are available for the control of purple blotch. Apply fungicides as the crop canopy ages and becomes more dense and if leaf wetness periods favour infection.

Stemphylium leaf blight (*Stemphylium botryosum*, *Stemphylium vesicarium*)

Stemphylium vesicarium lesions on an onion scape
Photo: Courtesy S. K. Mohan; Reproduced, by permission, from Schwartz,H. F. and Mohan, S. K. 2008. Compendium of Onion and Garlic Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Stemphylium leaf blight is usually found in association with other leaf diseases, such as purple blotch or downy mildew, but it has been reported to be a problem by itself. It appears to be restricted to the leaves of plants.

The fungus overwinters in infected crop debris from previous seasons. It attacks damaged, diseased or dying leaf tissue, and under ideal environmental conditions, it can cause serious damage to foliage. Disease development is promoted by humid, warm (18 to 25°C; 64 to 77°F) conditions and prolonged periods of leaf wetness (greater than 16 hours). Onion and garlic are susceptible.

Damage/symptoms
Initially, symptoms appear as small yellow to purple-brown, water-soaked lesions. These lesions later develop into oval to elongated, dark olive

brown to black spots when sporulation (spore formation) occurs. Large numbers of lesions can coalesce, leaving the leaves blighted and bleached.

Control/management

Currently, there are no fungicides registered for control of this disease, although protective sprays for botrytis leaf blight and purple blotch appear to provide some control of this pathogen as well. Taking care to manage these other foliar diseases will help in managing stemphylium leaf blight.

Rotate crops with non-susceptible crops for 3 years. Remove culls and volunteer onion and garlic plants from the field. Crop debris left from last year's crop should be buried through deep cultivation. If possible, increase plant spacing to facilitate air movement and quicker drying.

Irrigate crops during the late morning or early afternoon to allow leaf surfaces to dry more quickly and reduce the potential for infection and disease development.

Weed management

Due to their shallow, coarse root system, limited leaf area and generally slow growth rate, onions are poor weed competitors at all stages of growth. Even minor weed infestations can cause significant yield reductions. Control perennial weeds before planting onion crops.

Various herbicides registered for use in onions can be effective, particularly for controlling annual weeds and in higher plant densities. Use care in selecting products, with consideration given for crop rotations. Follow correct application timings to avoid plant injury.

Mechanical tillage can control some weeds if it is done close to the plants. However, this operation must be done with great care to avoid damaging the bulbs.

Other requirements

Sprout inhibition

In onions destined for long-term storage, the application of a sprout inhibitor (such as maleic hydrazide) is recommended. Maleic hydrazide is applied in the field to the growing crop after about 50 per cent of tops have fallen and plants have 4 to 8 green leaves, which typically occurs 10 to 14 days before harvest.

Plants must have at least four to eight leaves so that the sprout inhibitor can be properly translocated to the bulb. Premature applications of maleic hydrazide can reduce bulb quality. Application of sprout inhibitors will not improve the storability of poor-storing varieties.

Consult product labels for appropriate rates, timing and application methods for sprout inhibitors. Consult provincial specialists for currently registered products.

Harvesting

Harvest dry bulb onions when they are mature. Sprout inhibitors can be applied to long-storing varieties when tops start to go down (see notes above). Undercutting the roots will accelerate the maturation and dieback of the tops. Stop irrigation 14 to 21 days before undercutting. Bulbs may be lifted after 50 per cent of tops are down. If conditions are suitable, bulbs may be dried in the field, before placement in storage.

Dry bulb onions should not be allowed to freeze, which will begin to occur if temperatures fall below -1°C (30°F). Onions can tolerate down to -5°C (23°F) with minimal damage. If onions freeze in the field, allow them to thaw completely, reaching 4 to 5°C (39 to 41°F), before handling and harvest. Frozen product should be graded or culled heavily.

Harvest bunching onions starting when they are as thick as a pencil and show some slight bulb formation. Bunching onions are not typically stored for more than a few days.

Post-harvest handling and storage

Dry bulb onions store best at 0 to 1°C (32 to 34°F) and 65 to 75 per cent relative humidity.

Bulb onions may be cured after harvest by holding them at 32 to 35°C (90 to 95°F) with adequate ventilation for 10 to 14 days. Temperatures may be dropped to 26°C (79°F) after 7 days for the remainder of the curing period. Moisture loss during curing will be about 5 per cent by weight. At the end of curing, the outer skin and necks should be dry.

Initial ventilation rates during the curing period should be 35 to 40 litres per second per tonne (L/s/tonne) (70 to 80 cubic feet per minute per ton (cfm/ton)). After 10 to 14 days, reduce the rate by half.

At the end of curing, reduce the temperature gradually until it reaches the final storage temperature of 0 to 1°C (32 to 34°F), and reduce ventilation rates to 10 to 12 L/s/tonne (20 to 25 cfm/ton). Temperatures should not be lowered more than 2°C (3.6°F) per day to avoid condensation forming on the bulbs.

Improper or inadequate curing can result in serious losses due to neck rot and increased moisture loss in long-term storage. Maintenance of good storage conditions will allow dry bulb onions to be stored for 6 to 9 months.

Onions may be stored in bulk in 3- to 4-m (9- to 13-ft.) deep piles or in 500 to 1,000 kg (1,100 to 2,200 lb.) bulk boxes. Ensure sufficient air movement in the piles or boxes to maintain uniform humidity.

Spanish onions can only be stored for 1 to 4 months, even if proper conditions are maintained. Controlled atmosphere storage may allow the storage of Spanish onions to be extended, if necessary; however, this practice would not be typical.

Green bunching onions should be cooled within 4 to 6 hours of harvest to less than 4°C (39°F) to maximize quality. Green bunching onions are best stored at 0°C (32°F) and 95 to 98 per cent relative humidity. Under these conditions, they may be stored for 3 to 4 weeks. Storage at temperatures at or above 5°C (41°F) will reduce storage lifespan to 1 week.

Leafy and stem vegetables

Asparagus

Varieties/cultivars

A number of different varieties of asparagus are available to growers across the Prairies. Older varieties that are still available include ones in the "Jersey" series, such as Jersey Giant. Newer varieties include ones such as Guelph Millennium.

When selecting varieties, consider market and buyer demand and specifications, as well as such characteristics as disease resistance.

Climate and soil requirements

Asparagus is a long-term perennial crop. If properly managed, it can produce for 15 to 20 years. Management during the pre-planting and pre-production years is as critical as in the production years.

For asparagus, select land that has fertile, well drained, loam to sandy loam soil with abundant organic matter. Soil pH should fall between 6.0 and 6.8, if possible. The field should be free of perennial weeds. Before planting, soil test to a depth of at least 60 cm (2 ft.).

Asparagus grows best at temperatures between 16 and 29°C (60 and 85°F).

Due to the perennial nature of asparagus, the potential for the buildup of soil-borne pathogens is significant. Avoid planting into land that has previously been used to grow asparagus. If new land cannot be found, allow at least 5 years between asparagus crops,

Planting

Growers may produce transplants or crowns from seed, or they may purchase 1-year-old crowns. While crowns can help get the crop off to a faster start, they are more expensive and may harbour soil-borne diseases.

About 14,500 to 27,250 plants are required per hectare (5,800 to 10,900 plants/ac.), but some

New planting of asparagus in furrows (1- to 2- years old)
Photo: Robert Spencer

commercial producers plant up to 40,000 plants/ha (16,000 plants/ac.) with 120 cm (4 ft.) between rows and 20 to 25 cm (8 to 10 in.) between plants.

Planting from seed

Asparagus can be grown as transplant plugs in a greenhouse, seeded in a temporary location for 1 year and then replanted. Alternatively, it can be seeded directly into the permanent location. Seeding directly may save moving the plants the following spring, but as the seedlings are small and slow growing, they will require consistent weeding and watering if grown in the field.

Approximately 400 g (1.0 lb.) of seed should produce about 8,000 plants. Only strong plants should be used when transplanting. As many as one-half of the seedlings may need to be discarded because of weakness, disease, etc.

Seeding rates should be more than doubled when seeding directly. Producers may choose to purchase transplants from a supplier, rather than go to the work and expense of growing their own transplants.

Seed when soil has been well prepared and is above 15°C (59°F). Seeds may be soaked for 3 to 4 days before seeding. For transplant stock beds that will be moved, sow seed 2 to 3 cm (1 to 1.5 in.) deep, with seed spacing at 10 to 15 cm (4 to 6 in.) between plants and 60 cm (2 ft.) between rows. Alternatively, seed into 1.8-m (6-ft.) wide raised beds with 4 rows per bed and plants 7.5 to 10 cm (3 to 4 in.) apart.

If seeds are to be planted in their permanent location, sow seeds 2 to 3 cm (1 to 1.5 in.) deep in a furrow 15 to 20 cm (6 to 8 in.) deep. Plant approximately 12 seeds/m (4 seeds/ft.). Space the furrows 1.2 m (4 ft.) apart. Thin plants to 30 cm (12 in.) apart in the row (or final plant spacing) when emergence is complete. Fill in the furrows gradually as the plants grow over the course of the first growing season.

Planting from established plants
In early spring of the year following seeding, dig the year-old-plants, discard the weak plants, and plant vigorous crowns or transplants. Strong crowns should have at least 10 roots.

Plant the crowns or transplants 2 to 5 cm (1 to 2 in.) deep in a 20-cm (8-in.) deep furrow. Place the plants 30 cm (12 in.) apart in furrows spaced 1.2 to 1.5 m (4 to 5 ft.) apart. Spread the roots and cover them with not more than 5 cm (2 in.) of well firmed soil. Gradually fill in the furrows as the plants grow during the second growing season until the furrows have been filled level with the field.

Keep the asparagus bed free from weeds at all times.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Asparagus is a deep-rooted perennial that requires adequate nutrients in the root zone. Levels of relatively immobile nutrients such as phosphorus must be adjusted before planting.

The summer or fall before establishing an asparagus field, apply 44 t/ha (20 tons/ac.) of well rotted manure, or grow and incorporate a green manure crop. Either option will increase soil organic matter and reduce the annual fertilizer requirement. Additional applications (25 t/ha or 11 tons/ac.) of well rotted manure may be made every 3 to 4 years.

Before planting, apply and incorporate the following:

- 22 to 61 kg N/ha (20 to 55 lb. N/ac.)
- 121 to 160 kg P/ha (110 to 145 lb. P/ac.)
- 121 to 171 kg K/ha (110 to 155 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If banding P and K fertilizers, reduce rates to one-fifth and one-half, respectively.

For established beds, apply up to the following immediately after harvest:

- 61 to 99 kg N/ha (55 to 90 lb. N/ac.)
- 116 to 160 kg P/ha (105 to 145 lb. P/ac.)
- 248 to 292 kg K/ha (225 to 265 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

Application amounts should be reduced depending on nutrient levels determined by soil testing.

Irrigation

Asparagus requires about 25 mm (1 in.) of moisture (including precipitation) every 10 days throughout the season. Apply 50 mm (2 in.) of moisture after harvest and an additional 25 mm (1 in.) of moisture at the end of the season. Critical moisture periods are during establishment and during harvest.

Insect pest management

Asparagus aphid (*Brachycorynella asparagi*)

Although asparagus aphid is not common on the Canadian Prairies, other aphids occasionally feed on asparagus. Aphid feeding can cause damage to developing plants and reduce vigour in heavily infested plants, potentially leading to plant death within 2 years. Feeding can result in witches' broom-like growth and the production of many thin spears. Spring scouting is best to detect early infestations. Destroy or burn old fern growth.

Asparagus beetles (*Crioceris asparagi*, *Crioceris duodecimpunctata*)

Description/life cycle
There are two species of asparagus beetles: the asparagus beetle (*Crioceris asparagi*) and the more common spotted asparagus beetle (*Crioceris duodecimpunctata*). The asparagus beetle is 6 to 7 mm (about 0.25 in.) in length and black with

white-yellow markings along the outer edges of the elytra (wing covers). Spotted asparagus beetles are a similar size, but are bright red with small, black spots over the elytra.

Asparagus beetle adult
Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Spotted asparagus beetle adult
Photo: Manitoba Agriculture, Food and Rural Development

Damage/symptoms
Adult asparagus beetles feed on leaves in seedling and established beds, reducing vigour. Damage is typically only serious in early spring when adults feed on emerging shoots. Feeding that occurs later in the season has little effect on yields in subsequent years. Larvae feed within the berries, affecting seed production.

Control/management
Asparagus beetles are easily managed with insecticides, but this course of action is rarely needed. Little is known about natural enemies and their effects, if any, on asparagus beetle populations.

Disease management

Fusarium crown and root rot (*Fusarium oxysporum* f. sp. *asparagi, Fusarium proliferatum*, *Fusarium subglutinans*, other *Fusarium* species)

Description/disease cycle
Fusarium crown and root rot is often implicated in the progressive yield loss observed in many asparagus plantings over time.

Fusarium oxysporum f. sp. *asparagi* is a soil-borne fungus that survives as a hardened resting spore in soils often associated with root damage. It appears to be specific to asparagus and has no other hosts.

Fusarium proliferatum, which sporulates on the stems, and to a lesser extent *Fusarium subglutinans* are associated with crop debris and are not considered to be persistent in soil. Conidia (spores) are aerially dispersed by *F. proliferatum* and *F. subglutinans*.

Infection typically occurs at wounds created by insect feeding or mechanical damage at the base of the plant.

Propagation from infected crowns or seeds and transporting infected material to new production fields are common means of introducing the pathogen into new areas. Growing plants in soil infested with the pathogen can lead to infection of the roots followed by the spread of the pathogen through the vascular system of the plant.

Damage/symptoms
Initially, the fern foliage becomes chlorotic, followed by wilting, browning and the death of the plant. Examination of the lower stem internal tissue reveals a red to brown discolouration. Red-brown lesions develop near the base of a spear.

Fusarium crown and root rot damage in field
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Infected roots appear dark and soft. If plants are infected as seedlings, plant stunting and yellowed foliage often occur.

Infected plants may be scattered throughout the field, although low areas or slopes may be the first to have problems.

Most yield losses occur due to the weakened condition of the plant. Decay may continue after harvest, resulting in a reduced post-harvest shelf life.

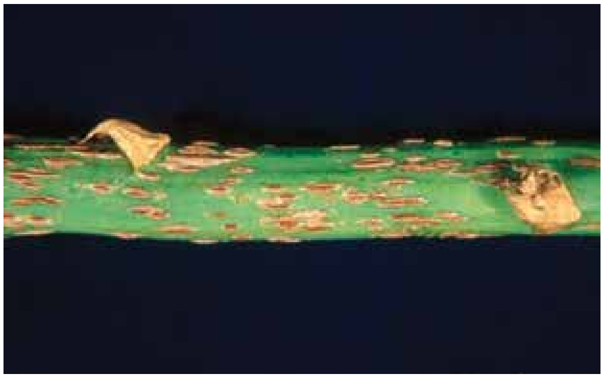
Control/management
Reducing stress on the plants is the best approach for managing this disease. The severity of the disease is influenced by poor drainage, low pH and prolonged dry conditions (after infection). Avoid cultivating deeper than 10 cm (4 in.) to prevent damage to the crown. Harvesting before crowns are properly and fully established as well as poor weed, insect, rust and blight control, and improper fertilization can all lead to a more severe disease effects because plants will be weaker.

Use seed or crowns that are free of disease. Plant into fields that have not had past problems or have been free of asparagus for at least 5 years. Rotations with grasses or cereals are also beneficial in breaking the disease cycle.

Fungicide seed treatments (if available) may help reduce outbreaks in seedlings.

Cultivars vary in their tolerance, but none have resistance to the pathogen.

Rust (*Puccinia asparagi*)



Red-orange pustules indicative of a rust infection
Photo: S. Johnston, Rutgers University

Description/disease cycle
Rust is a common disease of asparagus and may be found anywhere asparagus is grown. Due to the extensive defoliation that rust may cause, yield losses can occur for several years. Generally, rust is less of a problem in arid climates. The pathogen can also cause disease in onion and chive crops.

This pathogen has a complex disease cycle in which multiple spore types and fungal structures are formed. The complete disease cycle is restricted to infection on asparagus; unlike other rust species, no alternate host is required to complete the life cycle of *Puccinia asparagi*.

Damage/symptoms
As this pathogen produces several spore types, symptoms change throughout the season. Initially, pale green, 1- to 2-cm (0.4- to 0.8-in.) long, oval lesions develop, concentrated near the base of the shoot. These lesions eventually turn a cream to orange colour.

Elongated brown to red pustules are first observed on newly expanded shoots in late spring and early summer. The spores produced (urediaspores) can initiate new infections during the summer.

With the onset of cold temperatures or dry conditions, the rust-coloured pustules are replaced with black pustules (teliospores). The black pustules allow the rust pathogen to survive harsh conditions on infested crop residue and produce an air-borne spore in the spring to repeat the cycle.

Control/management
Remove and dispose of fern residues before the emergence of spears in the spring. Remove and destroy volunteer asparagus plants in or near asparagus fields as these volunteers have the potential to be infected.

Only plant asparagus in sites with good air circulation. Irrigate early in the day so that plants do not remain wet overnight.

Resistant cultivars are not available, although there are varying levels of tolerance in asparagus cultivars.

Weed management
Perennial weeds should be eradicated completely before planting or seeding asparagus. These weeds are difficult to control with chemicals within established asparagus fields, and deep cultivation may damage the asparagus crowns.

Some annual weed control can be expected by burial as the furrows are gradually filled in during establishment. Once plants are established (1 to 2 years), you can control annual weeds with registered herbicides. Alternatively, you can use shallow tillage over the entire crop before emergence and after harvest as well as between the rows.

Harvesting
Harvesting may be done on a limited basis starting in the third year after planting, depending on the age of the plant/crown that was planted. Planting crowns may shorten the time to harvest, provided there have been excellent conditions for plant establishment. It is important to allow crowns to establish fully before harvesting to maximize production and maintain crown strength over the long term.

In the first harvest year, cut all spears for only 2 to 3 weeks. In the second cutting year, harvest for about 3 to 4 weeks only. In the third and subsequent cutting years, harvest for about 4 weeks. In areas where more growth accumulates after harvest, asparagus may be cut for up to 6 weeks.

To maintain crop vigour, leave at least four healthy spears per crown after harvest. Excessive cutting in any year may seriously reduce crown vigour and reduce yields the following year. If this problem does occur, shorten the cutting season to let the crowns build up reserves to ensure a vigorous growth of spears the following year. Adjust harvests based on plant vigour and spear size, as well as the presence of disease, insect pests or poor growing conditions.

Spears are typically harvested twice a week, but in hot weather, a daily harvest may be required because of rapid spear growth. Harvesting is done either by snapping off or cutting spears at or just below the soil surface (12 mm; 0.5 in.). If cutting, use a clean, sharp knife.

Spears are considered mature and ready for harvest when they are about 12 to 20 cm (5 to 8 in.) high. Spear tips should still be closed. Spears should be straight, green and glossy. Older, larger spears are typically tougher.

Post-harvest handling and storage

Asparagus is extremely perishable and is normally marketed directly after harvest.

Asparagus should be cooled to 0 to 2°C (32 to 36°F) as quickly as possible following harvest. Delays in cooling will increase spear toughness and reduce the post-harvest lifespan. Cooled asparagus may be stored for up to 3 weeks at 0°C (32°F) and at a humidity exceeding 95 per cent.

Asparagus spears should be graded, trimmed and bunched soon after harvest. Spears are typically tied in 450-g (1-lb.) bunches and should be stored upright, with the bases of the spears on a water-saturated pad.

Other requirements

Post-harvest field care and disposal of ferns

The mature plant top of asparagus is a fern. After the cutting season, irrigate and allow ferns to develop for the remainder of the summer and fall. Ferns can be left to stand throughout the winter or can be clipped in the fall, leaving 15 to 20 cm (6 to 8 in.) of stubble to help in snow capture for the protection of overwintering crowns. This stubble or the old stalks can be removed in spring by mowing, burning or tilling lightly before spear emergence.

Celery

Climate and soil requirements

In the field after transplanting, celery grows best at temperatures between 15 and 18°C (60 and 65°F) and tolerates up to 24°C (75°F). Temperatures below 13°C (55 °F), particularly for prolonged periods, can induce bolting.

Celery can be grown on a range of soil types. It is particularly well suited to heavier soils that have excellent moisture-holding capacity. Irrigation is required for lighter soils (e.g. sandy or sandy loams). Soils should be well drained.

Planting

As a slow-maturing, long-season crop, celery is typically grown from transplants. Sow seed in the greenhouse about 10 to 12 weeks before transplanting into the field. Approximately 60 g (2 oz.) of seed should grow enough transplants for an acre.

Until plants emerge, maintain a temperature in the greenhouse of 21 to 24°C (70 to 75°F). Temperatures from 18 to 24°C (64 to 75°F) are ample for steady growth. Do not drop night temperatures below 13°C (55°F). Harden plants before transplanting by gradually withholding water beginning 7 to 10 days prior to transplanting. Do not use cold temperatures to harden the transplants.

Transplants should be placed in the field only when there is no risk of prolonged temperatures below 13°C (55°F); otherwise, bolting will occur. If plants are too tall at time of transplanting, they can be clipped back to 12 to 15 cm (5 to 6 in.). This practice may temporarily check plant growth.

Space plants 15 to 20 cm (6 to 8 in.) apart within rows that are 50 to 90 cm (20 to 36 in.) apart.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally, broadcast and incorporate the following:

- 116 to 160 kg N/ha (105 to 145 lb. N/ac.)
- 149 to 176 kg P/ha (135 to 160 lb. P/ac.)
- 165 to 198 kg K/ha (150 to 180 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If banding phosphorus or potassium, reduce rates to one-fifth and one-half, respectively.

Nitrogen at 24 to 36 kg/ha (22 to 33 lb./ac.) can be applied 4 to 6 weeks after planting, as a side-dressing or through the irrigation system. When applying granular fertilizers, take care to prevent the granules from lodging in the stems and leaves of plants as tissue burning can result.

An application of boron may be required to prevent cracked stems. It can be broadcast and incorporated (17 kg/ha; 15 lb./ac.) or applied as a foliar spray (4.4 kg/ha; 4 lb./ac.). Foliar applications of calcium (calcium chloride or calcium nitrate) can also be made; however, careful nutrient and water management can reduce this requirement.

Irrigation

Celery is relatively shallow-rooted, so frequent irrigation is required, especially on lighter soils. Celery plants must be provided with constantly uniform, high levels of soil moisture. Regular irrigation is essential in most areas to produce celery that is tender and free from "stringiness." Uniform moisture is also important in ensuring adequate amounts of calcium and other nutrients are taken up.

Insect pest management

Aster leafhopper (*Macrosteles quadrilineatus*)

Description/life cycle

The aster leafhopper's life cycle is described in Aster Leafhopper in the Carrots section. This insect is the main vector for the disease called aster yellows (see Aster Yellows in the Carrots section).

Damage/symptoms

Symptoms are often similar to those in carrots. Discoloured foliage is often the most notable symptom, but the celery may also develop a bitter taste.

Control/management

As with management in carrots, using yellow sticky cards or sweep sampling to determine aster leafhopper numbers is critical. Economic thresholds in celery are lower than in carrots, as celery is more susceptible to infection.

Lygus bug, tarnished plant bug (various *Lygus* species)

Lygus bug adult
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle

Various species of lygus bugs may attack celery. In some regions, the tarnished plant bug (*Lygus lineolaris*) is the dominant species. Lygus bugs overwinter as adults in sheltered sites and move into fields very early in the season to feed on whatever is available. There are typically two generations per year in the Prairies. Adults lay eggs in the plant tissues, and emerging nymphs feed on the host.

Damage/symptoms
Adults and nymphs will both feed on the main stalks of celery. Early season feeding causes relatively minimal damage. However as harvest approaches, feeding on parts of the petiole (stalk attaching leaf blade to stem) causes necrosis of leaflets and leaf bases, rendering the plants unmarketable.

Control/management
Lygus populations are widely present in the Prairies due to high acreages of canola and alfalfa, which are also hosts for these insects. So crop rotations and other cultural management practices have little effect on populations. Insecticides can provide adequate control during the latter part of crop growth, but are largely unnecessary earlier in the season. Currently, biological control provides little, if any, relief.

Disease management

Aster yellows (aster yellows phytoplasma)

Description/disease cycle
Aster yellows in celery is caused by the same phytoplasma that affects many other vegetable crops. While it may appear to be a significant problem, losses are generally quite low in celery. (For more information, see Aster Yellows in the Carrots section.)

Damage/symptoms
Symptoms on celery include chlorotic foliage, stunting and generally poor overall growth. The central portion of the plant may be necrotic. The petioles lose their typical flexibility, and the epidermis may crack or peel off from older plants.

A sure indication of aster yellows is the pronounced bending and twisting of the petioles that can vary from a slight curl to a tangled mess of petioles

Control/management
As this pathogen is vectored by a leafhopper, registered control measures for leafhoppers are the only real way to manage this disease. Even with pesticide applications, the incidence of aster yellows may not be reduced significantly.

Black heart (physiological disorder)

Black heart affected celery; note necrotic leaves in centre of plant
Photo: H.S. Pepin, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description
Black heart is a physiological disorder often associated with conditions that favour rapid plant growth, such as warm temperatures and excessive fertilization rates. Leaf margins may also have low levels of calcium.

Damage/symptoms
Symptoms appear on the leaf margins, with light to dark brown speckled lesions and necrotic portions. Interior leaves may develop these symptoms, with the heart of the celery becoming blackened.

Control/management
When possible, grow celery cultivars that are less prone to black heart. Do not use excessive amounts of fertilizer. Foliar-applied calcium supplements have met with limited success. Consider using irrigation systems, such as drip systems, to maintain more uniform moisture conditions over the course of the growing cycle.

Leaf blights:

Early blight, Cercospora blight (*Cercospora apii*)

Marginless brown lesions characteric of early blight (Cercospora blight)
Photo: L. MacDonald, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Early blight is a serious disease of celery. Under ideal conditions for disease development, it can cause extensive damage. Also known as cercospora blight, this disease usually appears earlier in the season relative to septoria blight (late blight). Temperatures of 15 to 30°C (59 to 86°F) and relative humidity near 100 per cent favour disease development.

This pathogen is both seed- and soil-borne and can survive as mycelium for over 2 years on seeds. It also overwinters on infected plant residues in the soil, initiating new disease outbreaks in the spring, both in the field and in seedbeds. The number of infected transplants will have a direct relationship to the development of disease in the fields.

Conidia (spores) may also be dispersed by field operations, such as using infested tools, moving through fields and splashing water.

High temperatures create favourable conditions for plant infection. Sporulation can occur from 5 to 14 days later. Due to the long production period for celery, numerous cycles of infection and sporulation can occur within a season.

Conidia are readily released during periods of increasing relative humidity. They can be dispersed over greater distances than the spores of late blight (septoria).

Damage/symptoms
Generally, older leaves exhibit symptoms before younger leaves do. Initially, round, chlorotic flecks are visible on both the upper and lower leaf surfaces. These flecks rapidly increase in size, enlarging to form brown to grey lesions, with no distinct border or margin, ranging in diameter from 1 to 2 cm (0.4 to 0.8 in.). Petiole lesions are more elongate, lengthening parallel to the petiole.

Under conditions of high relative humidity, lesions appear fuzzy, which is the first indication of sporulation and the release of spores from the lesions.

When disease pressure is high, entire plants appear blighted and discoloured. Severe infections can lead to necrosis and the death of entire leaves.

To distinguish between the two major leaf spots of celery, look for the following:

- Early blight lesions do not have black pycnidia (fruiting bodies) embedded in the leaf tissue.

- Early blight lesions are typically greater than 10 mm (0.4 in.) in diameter, whereas late blight lesions are less than 10 mm (0.4 in.).
- Early blight lesions do not have the defined borders typical of late blight lesions.

Control/management
Be sure to use clean seed. Consider using more tolerant cultivars in areas where early blight is a recurring problem. Rotate seedbeds if transplants are grown in the ground, and avoid overcrowding in seedbeds.

Irrigate earlier in the day to allow the foliage to dry quickly. Consider increasing plant spacing and/or widening rows.

Late blight, Septoria blight (*Septoria apiicola*)

Brown lesions of late blight in celery; note how lesions begin to coalesce creating large necrotic areas
Photo: L. MacDonald, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Septoria blight or late blight is a problem almost anywhere celery is cultivated. The fungus is seed-borne and can occur in severe outbreaks. As the name indicates, this disease typically occurs late in the season, after canopy closure, as the plants approach maturity.

Be aware that late blight in celery is not caused by the same pathogen as late blight on tomato and potato.

Infested seed is the primary source of infection by the fungus. Fruiting structures (pycnidia) may remain viable for as long as 2 to 3 years on seed when storage conditions are dry and cool (5 to 15°C; 41 to 59°F).

In seedbeds, the disease can develop from infested seeds and crop residues or be spread by contaminated tools and workers. Upon germination of the seed, any pycnidia attached to the seed coat may adhere to the developing cotyledons (first leaves) and lead to infection from conidia.

Within the field, diseased transplants, infested soil, contaminated items such as containers, tools or workers, or any activity that splashes water from plant to plant has the potential to initiate new outbreaks. Prolonged periods of rain and season-long overhead sprinkler irrigation can create severe epidemics. When conditions are such that plant growth is slowed, the pathogen can cause extensive damage in a relatively short time.

This disease can develop in storage as conditions ideal for storing celery also promote the survival of the disease.

Damage/symptoms
Initial symptoms include small, round to irregularly shaped chlorotic spots. These become necrotic (brown to black). Numerous black fruiting structures (pycnidia) appear. The pycnidia resemble grains of pepper in size and colour. On larger lesions, pycnidia are concentrated in the centre portion of the lesion; on smaller lesions, pycnidia occur throughout the lesion.

As the disease develops, the number of leaf spots increases. Chlorotic margins may be present around the lesions. As lesions increase in number, they begin to coalesce, creating large areas of brown necrotic tissue on the leaf. This development can result in the death of the entire leaf, including the petiole.

Symptoms typically appear on the lower foliage first, and then spread higher up on the petioles and leaves as the outbreak continues to develop.

Cultivars vary in susceptibility and symptom development. Lesions can take about 10 days to develop in the most susceptible cultivars, compared to 16 to 21 days for more tolerant cultivars.

Diseased petioles are not marketable and may be removed from the plant, resulting in reduced product size and quality as well as increased labour costs.

Control/management

Managing the disease in the seedbed is much easier and less costly than in the field.

Be sure to use pathogen-free seeds. Storing seeds for more than 2 years will generally eradicate the fungus, as survival is reduced beyond 2 years and unlikely past 3 years. As an extra precaution, disinfect celery seed with hot water before planting.

Remove any symptomatic plants from the greenhouse as soon as possible.

Maintain a two-year rotation away from celery, as the pathogen does not live long under field conditions in crop debris and soil. Be sure to destroy any volunteer celery plants in the field.

Fungicide treatments may be necessary if conditions conducive to disease development occur for prolonged periods. If disease pressure is high in the area, protective applications before symptom appearance may be necessary. Leaf wetness periods exceeding 12 hours have been used as a guideline to make fungicide use decisions.

Weed management

Competition from weeds can reduce celery yields and make harvesting more difficult. Control perennial weeds before planting. Use registered herbicides at appropriate times when necessary.

Other requirements

Natural compounds

Celery contains natural compounds that can cause skin rashes in sensitive individuals. Wear rubber gloves and leg protection when handling foliage or moving within the field.

Harvesting

Cut celery 2.5 to 5 cm (1 to 2 in.) below the crown, and trim off the coarse outer leaves.

Post-harvest handling and storage

Celery should be stored at 0°C (32°F) and more than 95 per cent humidity. When held under optimal storage conditions, a storage life up to 3 months can be expected, although celery is extremely sensitive to moisture loss. Storage in perforated plastic bags can be beneficial.

Do not attempt to store celery that has been damaged by frost, insects, disease or handling. Do not store with odorous products as celery will absorb flavours.

Hydro-cooling or vacuum-cooling is recommended when celery is marketed from the field.

Cole crops (cabbages, cauliflower, broccoli, brussels sprouts)

Varieties/cultivars

A wide range of varieties and cultivars exist for the different cole crops. Producers should select varieties that meet the needs of their customers and will yield a quality product within their climatic area. A range of varieties should be grown to spread out harvest and minimize the risks associated with production and harvest.

Cabbages of different colours may be grown for fresh consumption (early, mid- or late season crops), long-term storage or specialty markets, such as cabbage rolls or sauerkraut. Ethnic cabbages may also be produced for specialty markets.

Planting cabbage for the fresh market is staggered, following a targeted schedule to allow weekly harvests later in the season. Planting for storage cabbage is usually done over a shorter window of time to coincide with the projected harvest date. The early crops are transplanted while some of the late crops can be directly seeded into the field.

Cauliflower grown on the Prairies can be planted using a staggered schedule to allow weekly harvests later in the season. The early crops are transplanted while some of the late crops can be direct seeded. Cauliflower is primarily grown for the fresh market.

Broccoli grown on the Prairies can be categorized into early-season or late-season crops. The early crops are transplanted while some of the late crops can be direct seeded. Broccoli is grown for fresh consumption.

Brussels sprouts grown on the Prairies are only produced from transplants and are grown for the fresh market.

Climate and soil requirements

Cole crops are cool-season crops, thriving at temperatures between 15 and 18°C (60 and 65°F) and can tolerate up to 24°C (75°F). Cole crops grow best on well drained soils that are high in organic matter. Some of the cole crops (e.g. cabbage) are somewhat frost-tolerant.

Planting

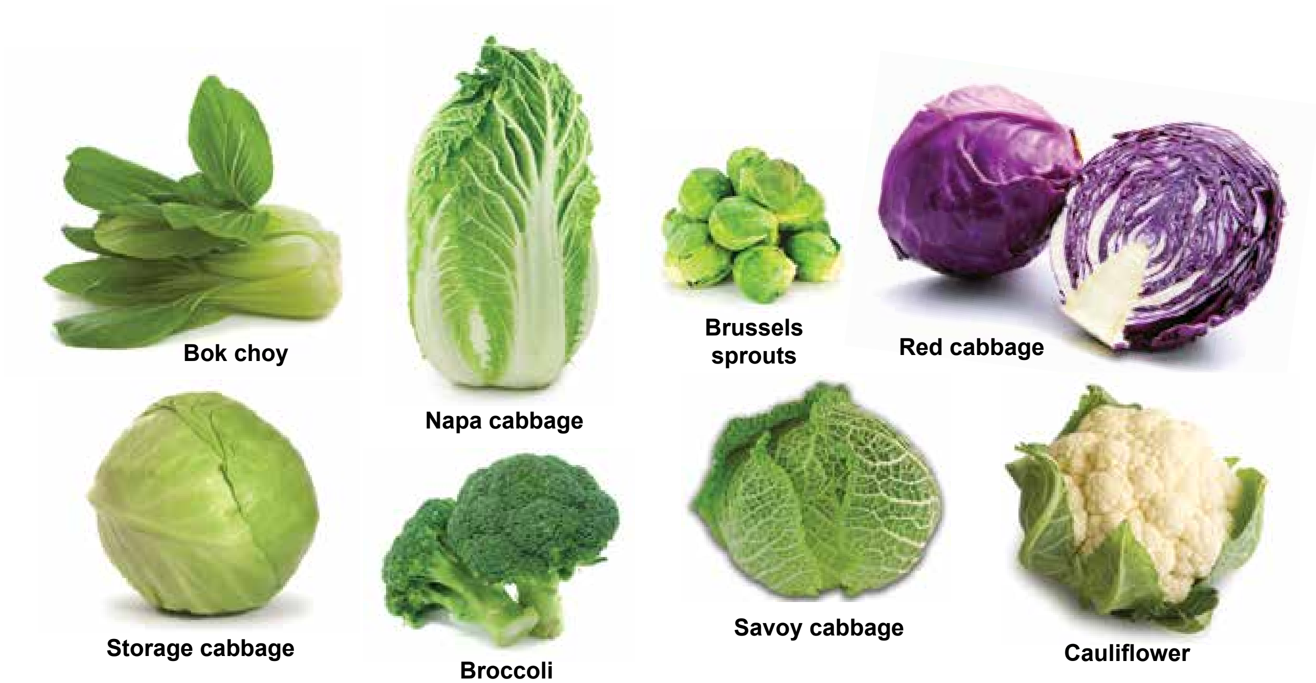
Seeding and transplanting

All cole crops, except brussels sprouts and some late cabbage, can be direct seeded in the field in most areas. Brussels sprouts require transplanting in all areas, and some late cabbage requires transplanting in some of the northern regions to reach maturity before frost.

Cole crops transplant well, and there are several advantages to transplanting these crops. The biggest advantage is earlier harvest dates. Normally, transplanted plants are harvested 3 to 4 weeks earlier than direct-seeded plants. Transplants assure producers of near-perfect stands with crops that tend to be more uniform in shape, size and maturity.

Transplants are also better able to withstand flea beetle damage relative to much smaller direct-seeded plants. Other advantages include a reduction in seed and thinning costs, particularly with expensive hybrids.

Some potential problems with transplants may include wind whipping (mechanical damage) and preferential feeding by root maggots.



A variety of different cole crops

Cole crops will germinate at relatively low temperatures (10°C; 50°F). Emerged seedlings and well hardened transplants are generally frost tolerant. Normally, cole crops can be field seeded or transplanted out between April 25 and May 15, depending on the location.

Typically, plants grown for transplants should be started about 4 to 5 weeks before placement in the field (about April 1 to 15). Brussels sprout transplants require about 6 weeks. Chinese cabbage is sensitive to extreme heat and should be transplanted early or seeded in mid-April or late June. Transplants should mature before extreme summer heat, and both early- and late-seeded crops will mature in cooler spring and fall temperatures.

Plant cole crops 1 to 2 cm (0.5 to 0.75 in.) deep.

For greenhouse seeding, 110 to 140 g (4 oz.) of seed provides enough cole crop transplants for an acre. For direct seeding, 2 kg/ha (1.8 lb./ac.) is required. If a precision seeder is used for direct seeding, about 0.48 kg/ha (0.44 lb./ac.) of seed is required.

Spacing

Table 32 lists row spacing and plant spacing for cole crops.

Table 32. Spacing requirements for cole crops

Crop	Row spacing		Plant spacing	
	(cm)	(in.)	(cm)	(in.)
Early cabbage	60 - 75	24 - 30	25 - 45	10 - 14
Mid-season cabbage	70 - 90	28 - 36	30 - 45	12 - 18
Late season cabbage	60 - 90	24 - 36	40 - 60	16 - 24
Cauliflower	60 - 90*	24 - 36*	30 - 45	12 - 18
Broccoli	45 - 75	18 - 30	15 - 45	6 - 18
Brussels sprouts	60 - 90	24 - 36	40 - 60	16 - 24
Chinese cabbage	60 - 75	24 - 30	30 - 45	12 - 18

* Widest spacings are acceptable for later plantings.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally, broadcast and incorporate the following:

- 61 to 99 kg N/ha (55 to 90 lb. N/ac.)
- 149 to 176 kg P/ha (135 to 160 lb. P/ac.)
- 165 to 198 kg K/ha (150 to 180 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If side-banding, reduce rates of phosphorus and potassium to one-fifth and one-half, respectively.

A portion of the nitrogen can be side-dressed or applied as a liquid through the irrigation system about 1 month after seeding or planting. A starter solution of liquid fertilizer (approximately 1 kg of all-purpose or rooting fertilizer per 100 L of water; 2 lb. per 26 US gallons) should be applied to transplants.

Boron deficiencies can occur in some areas under certain environmental conditions, particularly in dry weather. If boron deficiencies have been noted in the past or show up in soil tests, consider either broadcasting and incorporating 22 kg/ha (20 lb./ac.) of Borax before planting or making a foliar application of 4.4 kg/ha (4 lb./ac.).

Irrigation

Cole crops use about 380 to 500 mm (15 to 20 in.) of water in a growing season (including precipitation). Critical moisture periods are when heads are forming and enlarging. Maintaining uniform soil moisture can help prevent losses in quality, such as head splitting.

Insect pest management

Cabbage looper (*Trichoplusia ni*)

Description/life cycle

The cabbage looper does not overwinter in the Prairies. Most infestations are migratory in nature, occurring in the latter half of the growing season. Typically, only a single generation per year occurs after the migratory population arrives, but a second generation may be possible in the southern Prairies.

Cabbage looper pupa/cocoon
Photo: Manitoba Agriculture, Food and Rural Development

Cabbage looper larval instar
Photo: Manitoba Agriculture, Food and Rural Development

Cabbage looper adults
Photo: Manitoba Agriculture, Food and Rural Development

The adult moth has a silver marking on each forewing with a characteristic tuft of raised scales, resembling fur, on the forward portion of the thorax. The white eggs are laid singly or in groups near the edge of the underside of leaves and hatch within 3 to 4 days.

The larva is pale green with three white dorsal lines and a slightly larger white or pale yellow line on each side. Larvae move in a characteristic looping (inch worm) fashion and grow to 30 to 40 mm (1.2 to 1.6 in.) in length. The larvae feed initially on the underside of cabbage and cauliflower leaves but will feed in the flowers of broccoli.

Pupation occurs in a loose, woven cocoon attached directly to the plant. Pupae hatch after about 2 weeks.

Damage/symptoms
Most damage is done by the larger, later larval instars. Economic damage occurs on the underside of cabbage and cauliflower heads and the flowers of broccoli. The presence of larvae or their waste products renders the produce unmarketable.

Control/management
Monitoring for this and two other caterpillars, the diamondback moth and imported cabbageworm, can be done visually. The moths are most active in the early evening. Pheromone traps may be used to monitor cabbage looper moths, but in years when migrations are minimal, the traps may not catch any moths.

The cabbage looper can be difficult to control with insecticides as the pest often carries chemical resistance picked up in southern growing regions. First through third instar larvae are more easily controlled with chemical applications. Later instars require higher concentrations. Economic damage thresholds vary with the crop and the end use of the crop.

Similar species: Alfalfa looper (*Autographa californica*)
In Alberta, the alfalfa looper may be more common than the cabbage looper. The alfalfa looper attacks cole crops as well as various other

crop types. Adults emerge early in spring from overwintering pupae and lay eggs directly on plants. Appearance and life cycle are generally the same as described for the cabbage looper but with two generations per year.

Cabbage maggot (*Delia radicum*)

Cabbage maggot larva
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
Populations of cabbage maggot are everywhere in the Prairies owing to the high acreages of canola, which is also a host. Pupae overwinter, and adult flies emerge early in spring, often coinciding with the bloom of Saskatoon berry bushes. There may be up to three generations per year.

Eggs are laid on the soil surface near the host plant. The maggot larvae feed on the fine root hairs of the plant and later burrow into the taproot.

Damage/symptoms
Larval feeding on the roots causes the primary damage. In crops like cabbage, cauliflower and broccoli, feeding may cause the stunting of young plants. Large plants may have reduced growth, lower yield and/or lower quality. In root crops like radish, rutabaga and turnip, the scars left by the maggots' attack renders the roots unmarketable.

In some situations, maggots may tunnel into the heads of cabbage, resulting in storage and marketing issues.

Control/management
Monitor the arrival of the adult flies with yellow pan traps or yellow sticky traps. For chemical control, apply insecticides as in-furrow and post-planting treatments. Late plantings of broccoli, cabbage and cauliflower may not need insecticide treatment, but early plantings often do. Radish, rutabaga and turnip all need at-seeding treatments to provide adequate protection. Be sure to follow the pre-harvest interval requirements for any products applied.

Physical barriers (crop covers or fine fencing) may provide some degree of control. Insecticide treatment may still be necessary. No biological control options are currently available.

Cabbage maggot damage
Photo: Manitoba Agriculture, Food and Rural Development

Cabbage seed pod weevil (*Ceutorhynchus assimilis*)

Description/life cycle
The cabbage seed pod weevil is currently found in the western Prairies. It will likely continue to expand its range into eastern Saskatchewan and Manitoba.

There is a single generation per year. Adults overwinter and become active in May or June. Oviposition (egg laying) does not take place early in the season as adults feed on nectar and pollen for about 30 days before the onset of oviposition.

Eggs are deposited singly in the seed pods and hatch into larvae. The larva is 3 to 4 mm (0.12 to 0.16 in.) in length with a white, wrinkly body, a black head capsule and no apparent legs. Larvae feed within the developing seed pod and drop to the ground to pupate at maturity.

Damage/symptoms
At this time, there appears to be limited potential for this pest to affect vegetable crops as damage is typically limited to seed crops.

Control/management
Cleaning up cruciferous weeds and volunteers will aid in reducing general populations. Insecticide treatments are often effective, but given the adults' preference for feeding on floral structures, extra care must be taken to protect pollinators.

Diamondback moth (*Plutella xylostella*)

Diamondback moth larva
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Description/life cycle
The diamondback moth is a migratory pest arriving from the US on southern airflows. Populations are variable from year to year, and the pests may arrive as early as April.

The adult holds its grey-brown wings folded over its back (diamond-shaped cross section) and has characteristic silvery white patches along the back when at rest. Eggs are yellowish to pale green and are laid singly or in small groups, typically on the upper leaf surface (contrast with the cabbage looper, which lays its eggs on the underside of the leaf).

Eggs hatch in 4 to 6 days, and larvae feed on the lower leaf surface for 10 to 14 days. Larvae are hairless, green to greyish green caterpillars that reach 12 mm (0.5 in.) in length. Small larvae may be distinguished from other larvae by their wriggling behaviour and dangling from a silken thread when disturbed. Pupation occurs on the plant.

Diamondback moth adult
Photo: Manitoba Agriculture, Food and Rural Development

It takes about a week before another generation of adults emerge. A dramatic increase in numbers can be seen between generations under suitable environmental conditions.

Damage/symptoms
First instar larvae mine the leaf tissue. Older larvae feed on the lower surface causing irregular holes in the leaf tissues. The upper leaf surface usually remains intact and in heavy infestations, has a silvery appearance. Older larvae may also bore into florets of broccoli and cauliflower as well as the edible parts of brussels sprouts and cabbage. The larvae may occasionally damage the crown of rutabaga.

Control/management
Early season monitoring with pheromone traps is useful in determining the arrival of this pest and pest populations. Note that diamondback moth populations that are considered small for canola production can cause significant problems in vegetable cropping systems.

This pest has numerous natural enemies that may help keep populations below damaging levels. When these enemies do not provide sufficient control, insecticides often provide excellent control. As a migratory pest, the diamondback moth may carry with it resistance to certain insecticide groups inherited from its ancestors in the southern growing regions.

Flea beetles (various species)

Flea beetle adult on cabbage seedling with characteristic shot hole damage
Photo: Robert Spencer

Description/life cycle
There is only a single generation per year of the flea beetles, beginning with the emergence of overwintering adults early in the growing season. In late May through early July, eggs are laid in the soil near the roots of host plants. Larvae feed on the roots of host plants, though this feeding seldom causes economic damage. Adults emerge in late July and feed on the cotyledons and leaves of any cruciferous hosts available.

In years when canola is swathed early, tremendous populations of flea beetles will migrate out of the canola fields and into adjacent vegetable crops causing significant damage just before the harvest period.

Damage/symptoms
Adult feeding causes characteristic shot hole damage. Heavy feeding pressure can retard growth or even kill newly emerged seedlings. Damage can be as a result of direct feeding or reduced vigour.

Field damage from flea beetle
Photo: Manitoba Agriculture, Food and Rural Development

Control/management
Monitoring of populations visually can indicate if control measures are necessary.

Treatment with insecticides at planting or upon emergence helps protect the vulnerable seedlings against excessive flea beetle damage.

Later in the season, the larger plants are capable of withstanding considerable flea beetle pressure without appreciable yield loss. However, the obvious signs of flea beetle damage may reduce the visual appeal of the product.

Foliar-applied insecticides can be used to manage late season flea beetle infestations. Pay attention to the pre-harvest interval requirements of any pesticide applications, particularly the late season applications.

Imported cabbageworm (*Pieris rapae*)

Imported cabbageworm larva
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Imported cabbageworm adult
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle

Imported cabbageworm overwinters in Canada, typically in the pupal stage. There may be up to three generations per year on the Prairies. Populations are extremely variable from year to year as natural enemies can provide very effective control of this pest insect.

Adults are white butterflies that lay eggs singly along the midrib on the underside of the host plant. Larvae are pale green caterpillars with a yellow-orange stripe along the middle of the back and short white hairs covering the body giving it a velvety or hairy appearance. Larvae can grow to 30 mm (1.2 in.) in length. The pupa or chrysalis is quite distinct from that of the diamondback moth or cabbage looper and varies from green to brown.

Damage/symptoms

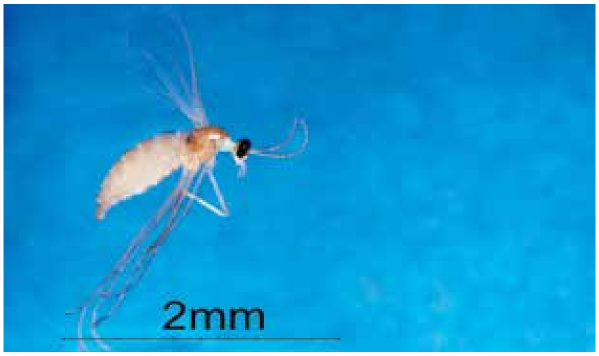
Larvae cause damage by chewing leaves and can create large holes. Larvae will also move into the base of the plant head to feed, rendering it unmarketable due to the feeding damage and copious production of frass. Plants can tolerate feeding damage to outer leaves, but the presence of frass contaminates and renders the produce unmarketable.

Control/management

In most years, natural enemies keep this pest well below economic threshold levels, but occasional outbreaks can cause tremendous damage. Visual scouting is most effective in conjunction with checking for other lepidopterous pests (moths and butterflies).

Chemical controls applied to the larvae can be extremely effective until the larvae have made their way into the plant's head where they are often well protected and unaffected by insecticide applications.

Swede midge (*Contarinia nasturtii*)



Swede midge adult
Photo: Susan Ellis, USDA APHIS PPQ, Bugwood.org

Description/life cycle
Currently, swede midge is uncommon in the Prairie provinces, but there is concern about its potential to spread and become established.

The life cycle in western Canada is not well documented; it is better understood in eastern growing regions.

The adult is a small midge fly that feeds on a variety of cruciferous vegetables in addition to canola. It is light brown and 1.5 to 2 mm (0.06 to 0.08 in.) long. Adults emerge from pupal cocoons in the soil in late May to early June and oviposit on suitable hosts, with eggs laid in clusters on young growing parts of the host plant. Larvae are tiny and feed in groups near the growing point.

There are multiple, overlapping generations in eastern Canada, and the adults remain active until a hard frost.

Damage/symptoms
Damage is a direct result of larval feeding and is often quite obvious, although it may be confused with nutrient deficiencies, herbicide injury, heat stress or frost stress. Symptoms include deformation of heart leaves, closed and swollen flower buds as well as deformed, disjointed or asymmetrical heads. The production of secondary stems may occur where stem tissue has been severely affected.

Swede midge damage to cabbage
Photo: Julie Kikkert, Cornell Cooperative Extension, Bugwood.org

Control/management
Monitoring is best achieved with swede midge pheromone traps.

Crop rotation is an effective tool for managing this pest as the midge is a poor flyer, but canola cannot be used in the rotation as it is also a host for the midge. The rotation must be long because the midge can remain viable in the soil as a pupa for 2 or more years.

Field sanitation in affected fields is also critical.

Insecticide management is the only current in-crop treatment available.

Thrips (various species such as *Thrips tabaci*)

Description/life cycle
The life cycle of thrips (egg to adult) is completed in about 2 weeks. There are, however, typically only two generations per year in the Prairies. Hot, dry weather strongly favours thrips populations. Cereals can serve as hosts for thrips, and the harvest of cereals often leads to a migration from the cereal crop into adjacent vegetable crops.

Eggs are laid in the foliage and hatch within 5 to 7 days. Nymphs resemble adults but have no wings. They are typically colourless, whitish or yellowish. Nymphs take 8 to 10 days to develop; they then drop to the soil, pupate and emerge as the winged adults. Adults are variable in colour and may be whitish-yellow to black.

Damage/symptoms
Thrips feed in sheltered locations on the plants, and once inside the wrapper leaves, they cannot be affected by traditional contact insecticides. New systemic products can potentially provide some control.

Thrips feeding damage appears as whitish scratches or brown blisters on the foliage or as patches on the heads. Thrips are most damaging to cabbage and cauliflower. The presence of thrips or thrip damage reduces marketability.

Control/management
Avoid planting crops close to or downwind of small grains, clover or alfalfa, which all serve as alternate hosts. Tight-headed cabbage varieties are

preferred by thrips. Contact insecticide treatments are best applied before the plants form a tight head.

Other insect pests
Cole crops may be affected by a number of other insect pests, including aphids, cutworms or other common pests. While these pests are not problematic in most years, monitoring of their populations is still required, so control measures can be taken if necessary.

Disease management

Alternaria leaf spots: grey leaf spot (*Alternaria brassicae*); black leaf spot (*Alternaria brassicola*)

Alternaria leaf spot lesions on brussels sprouts
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Grey and black leaf spot fungi may survive on the surface or the internal tissues of seeds. The grey leaf spot pathogen (*Alternaria brassicae*) loses viability after a few months, whereas the black leaf spot pathogen (*Alternaria brassicola*) can survive for as long as 12 years in internal tissues. Infected seed will usually have reduced vigour and germination rates. Necrotic lesions on cotyledons may result in the stunting or death of cotyledons.

The fungi also survive on crop residues as microsclerotia (small knot of cells) or in the soil as hardened resting spores. Spores may originate from infected cruciferous weeds and volunteers.

Sporulation can occur in 90 per cent relative humidity and moderate temperatures of 18 to 24°C (64 to 25°F). Spores are dispersed via water splash and wind. Older leaves are more susceptible. The pathogen requires 6 to 8 hours of moisture as well as prolonged warm temperatures for disease outbreaks to occur.

Harvesting of canola or other infected crucifers can enable air-borne spores to be carried by wind to vegetable plantings. Black leaf spot (*Alternaria brassicola*) has been reported to be spread by insects as well.

Damage/symptoms
The two pathogens can infect all above ground parts of the plant. Initially, foliar symptoms can appear as minute dark spots. As these spots enlarge, they become grey to brown. As the lesions expand, they may appear as round spots or take on an angular appearance when near leaf veins. Lesions may have a purple to brown border or a chlorotic halo if the leaf is still green.

As the lesions mature, they take on a target appearance. As the lesions dry out, the centre may tear, giving the lesion a “shot hole” appearance.

Grey leaf spot appears as small, light brown to grey-brown lesions, whereas black leaf spot lesions are large, olive and grey to grey-black.

Control/management
Treat seed with hot water or a fungicide to minimize the effect of surface seed infections. Internal seed infections are not controlled by protective fungicides.

Destroy crop residues, avoid planting vegetable *Brassica* crops near oilseed *Brassica* crops, such as canola, and eradicate cruciferous weeds. Foliar fungicides can provide some control.

There are differences in cultivar susceptibility. No known broccoli cultivars are resistant to the head rot phase.

If a cabbage crop is expected to be stored for an extended period, leaf spots on the cabbage head should be controlled. Begin regular applications of protective fungicides in the middle of the growing season. If conditions are warm and wet, this treatment protocol may prevent disease outbreaks.

Blackleg, phoma leaf spot (*Phoma lingam/ Leptosphaeria maculans*)

Dry rot lesion characteristic of blackleg
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Blackleg disease is a significant problem on cruciferous oilseed crops on the Prairies, and it also affects various cruciferous vegetables. *Leptosphaeria maculans* has both sexual and asexual reproductive phases; *Phoma lingam* is the name of the asexual reproductive phase.

The fungal pathogen can be seed-borne, and low levels of the pathogen (less than 0.1 per cent) can initiate outbreaks. Air-borne spores (ascospores) can also travel more than a kilometre. This characteristic can pose serious challenges to production because infected canola debris is the chief source of wind-borne inoculum.

Once the first infections occur, as little as 3 to 4 days at 20°C (68°F) are required for the first phoma leaf spots to appear. Once spots are present, rain splash disperses spores from plant to plant.

Damage/symptoms
Green-brown leaf spots develop first, later becoming tan or nearly white. Spots are round or oval and may range from 0.5 to 3.0 cm (0.2 to 1.2 in.) in width. Close observation will reveal the presence of black dots (pycnidia) within the lesions. A yellow halo may appear around the margin of the lesion. Any leaf veins that pass through the lesions may appear black.

Main stem symptoms appear as large, sunken, elongated, brown to black cankers, with uneven margins. If enough tissue degrades, stem girdling and plant death may occur, especially in seedling infections. Generally, poor growth, stunting, wilting and delayed maturity may occur in plants with stem cankers. Cankers may also form from spores that infect the hypocotyls (stems of germinating seedlings) at the soil surface.

Blackleg and phoma leaf spot are now considered to be caused by a complex of pathogenicity groups (PG2, PG3 and PG4). Pathogenicity refers to the ability of a pathogen to cause disease. The ability to cause disease in specific cultivars may differ from one pathogenicity group to another.

This characteristic has implications for the evaluation of resistant and tolerant cultivars, as cultivars once considered to be tolerant of infection may not have been exposed to each of the pathogenicity groups. A less virulent form of blackleg is now considered a separate species (*Leptosphaeria biglobosa*).

Control/management
A four-year rotation away from *Brassica* crops is recommended. Avoid planting near canola fields as air-borne spores from diseased crop debris or crops are a significant source of inoculum. Keep fields free of cruciferous weeds. Maintain good soil drainage. Plough down all crop residue.

To manage blackleg and phoma leaf spot, use clean seed or treat with fungicides or hot water.

There are no known resistant cultivars, but some *Brassica oleracea* crops show considerable tolerance to the leaf infection phase. Most cabbage, Chinese cabbage, brussels sprouts, radish and rutabaga cultivars are susceptible. Cauliflower and broccoli are moderately susceptible.

Foliar fungicides are often necessary in wet and moist areas as well as for crops near canola fields.

Black rot (*Xanthomonas campestris* pv. *campestris*)

Typical angular lesions of black rot
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Black rot is a serious bacterial disease of *Brassica* crops. The bacterium can spread rapidly in the field. It may be seed-borne and may also be present in *Brassica* weeds and volunteers.

While the pathogen may be present in the field on leaves, conditions such as high humidity and water splash are necessary for the bacterial population to increase and cause significant damage. Rain and overhead irrigation favour the spread of the pathogen.

Cotyledons and leaves are colonized through hydathodes (leaf openings) on the leaf margins. Infections may also occur through wounds or roots. The bacterium cannot survive in the soil for an extended period.

Damage/symptoms
Symptoms can vary depending on the *Brassica* host. Initially, small, water-soaked leaf spots develop. These small spots later change to brown specks with a chlorotic margin, similar in appearance to other bacterial diseases. Angular or v-shaped chlorotic lesions often develop along the leaf edges.

With the onset of dry conditions, the lesions dry out and become tan or brown. Within the lesions, black leaf veins may occur. Severely damaged leaves may drop from the plant.

Systemic infection of the stem and vascular tissues of petioles may cause black discolouration of the stem. On cabbage and brussels sprouts, the infection may spread through the veins into the head, rendering the product unmarketable.

The occurrence of black veins in a yellow lesion along a leaf margin is diagnostic for black rot. A cross-section of an infected stem will reveal a black vascular ring.

Control/management
Cull piles of rutabaga and other cruciferous crops should not be located near production fields or storage units. Turn under any crop residue in the field soon after harvest. When residues have broken down, the bacterium will not be able to survive. Crops should be rotated to non-crucifers for at least 3 years.

Both sprinkler irrigation and working in wet fields contribute to infection spread. Use drip irrigation or apply water so as to encourage rapid drying. Do not work fields when plants are wet.

Choose resistant or very tolerant cultivars. Use clean or treated seed.

Disease spread often occurs in the seedbed. Therefore, watch for any transplants exhibiting symptoms and discard them as well as adjacent plants. Trimming transplants increases the risk of pathogen spread.

Foliar fungicide application is generally not effective for black rot control.

Lethal yellowing, fusarium wilt, fusarium yellows (*Fusarium oxysporum* f. sp. *conglutinans*)

Description/disease cycle
The above-named pathogen is soil-borne and produces hardened structures known as chlamydospores. This disease has been known to be seed-borne as well.

Infection starts in the roots. Upon penetration of the vascular system, pathogen growth and sporulation occur. Local and long distance spread can occur through wind-borne soil, drainage water, soil adhering to equipment, infested seed and diseased seedlings.

Damage/symptoms
Lower leaves on one side of the plant may exhibit yellowing (attributed to the activity of a toxin produced by the pathogen). Leaves turn brown and fall from the plant. The xylem (transport tissues) in the main stem and larger petioles appear tan to brown, which is a characteristic symptom of this disease. Entire plants may wilt. This disease typically develops between temperatures of 24 and 39°C (75 and 102°F).

This disease can also be a concern on radish, with symptoms characterized by a dull green chlorosis of the leaves followed by a general yellowing of the plant and death of the leaves. Growth is stunted, and brown to black discolouration in the central core of the radish root may occur.

This disease may resemble black rot. However, in lethal yellowing, the stain in the vascular system is brown rather than black.

Control/management
Avoid using infested seedlings or seed. Prevent movement of infested soil into fields because once introduced into a new area, this pathogen will be present for years.

If the disease has been observed in a field previously, the best strategy is to use resistant cultivars, if available. Resistance to this pathogen is influenced by temperature. “A” type resistance prevents pathogen invasion of the vascular system up to 30°C (86°F). “B” resistance does little against invasion of the vascular system at high temperatures, but becomes more effective as temperatures decrease.

Potassium deficiency appears to increase disease severity. Ensure fertilization is balanced and adequate for healthy plant growth.

Rhizoctonia, wirestem, damping-off (*Rhizoctonia solani*)

Wirestem in cabbage seedling; note pinched, brown appearance of root
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Rhizoctonia solani is a common fungus that survives in soils as dormant mycelium or hardened sclerotia. The fungus may be carried in or on the surface of most *Brassica* seeds. Pathogen-infested soil can also be spread on plant debris or by wind, water or machinery.

Disease development is favoured by soil temperatures of 25 to 30°C (77 to 86°F). However, problems can occur over a wide temperature range. Soil nutrients and crop residue can act as energy sources to sustain the fungus when no susceptible crop is planted.

If a plant is infected and the stem is constricted and twisted but the plant is still upright, the symptoms are called wirestem. Most often, the girdling of the stem at the soil line causes seedlings to fall over, wilt and die; these symptoms are called damping-off.

The pathogen may be observed in the field as rough mycelium that causes soil particles to dangle from the fungus.

Damage/symptoms

With wirestem, the plant stem darkens above and below the soil line. The outer cortex decays and is sloughed off in sharply defined areas encircling the stem. The stem is wiry at the lesion. As the stiffened stele (central part) of the stem provides structural support, the plant remains upright. After transplanting into the field, the plant is unproductive, stunted and may die.

Plants as tall as 10 to 15 cm (4 to 6 in.) may be attacked.

For damping-off and wirestem, the stem adjacent to the soil develops a dark, water-soaked, brown discolouration. Older seedlings may have cracks in the epidermis, lesions and outer stem tissue decay. Only the fibrous inner xylem remains after the stem deteriorates. Diseased plants may wilt, turn purple and remain stunted. The seedling may snap off at the soil line.

Cauliflower is more susceptible to this disease than cabbage or brussels sprouts.

Control/management

Planting healthy seed with good vigour and germination qualities is very important. Treat seeds with hot water or a fungicide to help reduce the introduction of *Rhizoctonia solani* to the field.

To prevent damping-off and wirestem in seedbeds, use only sterilized soil or soil that has not previously supported crucifers. Wirestem on cabbage seedlings may develop into bottom and head rot, so do not transplant affected seedlings into the field.

Avoid deep planting and planting into excessively cold or hot, moist or saline soils as these conditions can promote seed decay and pre-emergent damping-off.

Decrease plant density to allow adequate light penetration and air circulation. When watering, apply early in the morning on sunny days to promote rapid drying of the foliage. Avoid overwatering. Do not hill or mound soil onto the lower leaves of the plants.

Ensure that nutrients are available to the plants in sufficient quantities. Deficiencies in calcium, potassium and nitrogen, or excessive nitrogen promote wirestem.

Maintain a rotation with at least 3 years of non-crucifers.

Root crops such as turnip, rutabaga and horseradish with only slight infections may be safely stored at low temperature.

Sclerotinia rot, sclerotinia drop, watery soft rot (*Sclerotinia sclerotiorum*)

Black sclerotia of *Sclerotinia sclerotiorum* formed in stem cavities of oilseed rape
Photo: Courtesy G. A. Petrie; Reproduced from Rimmer, S. R., Shattuck, V. I. and Buchwaldt, L. 2007. Compendium of Brassica Diseases. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Sclerotia from previously infected crops are the primary source of inoculum, although infected seed lots can also be a source of infection. The pathogen can survive in the soil for 3 to 4 years, depending on weather conditions.

In crop residue, sclerotia may develop even after the residue is buried and may go into a period of dormancy. Sclerotia that are buried deeply in the soil generally do not germinate, whereas those near the soil surface germinate into fruiting bodies called apothecia.

Apothecia produce wind-borne spores (ascospores), which can be carried from field to field. Reports indicate that honeybees may aid in the spread of ascospores if the spores adhere to pollen; however, it is uncertain how significant this mechanism is in the disease cycle.

The stem rot phase of the disease develops chiefly from the ascospores. However, spread between plants that are severely lodged can also lead to stem rot. Any part of the foliage that comes in contact with sclerotia can become infected, especially stem bases, which are in constant contact with the soil. New sclerotia are produced within spaces in the rotting stem and on heads.

Damage/symptoms
Initially, infection of the plant near the soil surface results in decay of the stem. This infection progresses upward in the plant, killing leaves in succession and causing them to fall off. Downward spread of the infection results in root decay. Once the head is infected, it turns into a slimy mass, referred to as soft rot.

Soft rot of cabbage head caused by sclerotinia rot: not to be confused with bacterial soft rot
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Many sclerotia are formed between the collapsed leaves and the lower surface of the outer leaves. When dry, a brown canker forms around the base of the stem, which may rapidly kill the plant without the soft rot phase on the head.

White mould can develop in storage as well, on seemingly healthy plants. Clumps of white, cottony mycelium and black sclerotia are occasionally formed.

Control/management

When this disease infests a field, destruction of sclerotia is very difficult. Soil tillage usually moves sufficient sclerotia to the soil surface to initiate disease if environmental conditions are favourable.

Plant in well drained soil. Use a plant spacing that will allow good air circulation among plants. Maintain rotations with at least 3 years of non-susceptible crops, such as grasses, cereals, beets, onions, spinach, corn, etc. Remove and destroy diseased plants. Eliminate weeds because many are also affected by *Sclerotinia sclerotiorum*.

Harvested produce should be kept in clean bins free of dirt. Storages and storage bins should be well ventilated, disinfected and steam sterilized. If the infection appears during storage, be sure to remove infected heads to prevent spread of the rot to adjacent healthy heads.

Foliar fungicide application of fungicides can help. There is a commercially available bio-control product that uses *Coniothyrium minitans*, a fungus antagonistic to sclerotinia.

Currently, no resistant cultivars are recognized.

Soft rot (various *Erwinia* species)

Soft rot is common in many crops. See the General Diseases section under Disease Management in the Pest Management chapter for details.

Control/management

Avoid mechanical injury during cultivation and harvesting. Control root maggots, slugs and chewing insects. Minimize frost injury.

Use plant and row spacings that allow good air circulation. Avoid excessive nitrogen applications. Prolonged overhead irrigation may increase infection.

Disinfect storages (see Sclerotinia Rot section above), and maintain proper temperature and adequate airflow in storage.

Weed management

Due to their close genetic relationship to cole crops, weeds that are members of the mustard family (e.g. stinkweed, shepherd's-purse) cannot be chemically controlled in cole crops. Adequate crop rotation in previous years or cultivation in the growing season will be required to control these weeds.

Cole crops are particularly sensitive to residues of some soil-applied herbicides. Consider chemical residues when planning crop rotations. In situations where applications of any of these products occurred late in the previous season, rotate to non-cole crops.

Other requirements

Cauliflower blanching

Be sure to market only white, compact heads of cauliflower. Heads that develop during hot weather and are exposed to sunlight become yellow and unmarketable.

Three methods are available to help reduce the yellowing of cauliflower:

- **Tying heads with elastic or string:** When the cauliflower head is small, it is naturally covered by leaves. However as the head expands, the covering leaves are pulled away, and the head becomes exposed to light, resulting in yellowing. To prevent this yellowing, the large outside leaves of the plants can be tied over the small head.

  Since plants will be ready for tying at different times, use different coloured ties on each day. A few plants of one colour tie can be checked, and if mature, the entire lot can be harvested without checking each plant. Head tying works well, but it is not practical in large plantings as the practice is very labour intensive.

  Breaking two or three of the larger inside leaves over the head is quicker than tying. However, this technique generally does not provide the same effective protection for the developing head as tying.

- **Crowding plants:** Another option is to reduce the between-row and in-row spacings. By planting cauliflower in rows 60 cm (24 in.) apart and spacing plants 25 to 30 cm (10 to 12 in.) apart in the row, the outside leaves will tend to grow in a more upright position. This more intensive, upright leaf growth shades the developing curds more than if the plants are farther apart, resulting in less yellowing of the heads. However, crowding may delay maturity, reduce the average head size and promote the development of disease. This method is recommended on a trial basis only.
- **Using self-blanching varieties:** Some newly developed cauliflower cultivars produce leaves that keep the heads protected from sunlight through to maturity. This development represents a major savings in the labour required to tie the crop.

Brussels sprout development
In some years, a portion of the sprouts may fail to develop adequately before harvest. The development of sprouts can be improved by pinching the growing point of the plants when the middle sprouts are about 1 to 2 cm (0.5 to 0.75 in.) in diameter (early August). This practice improves uniformity and promotes maturity, which are desirable for a single once-over harvest.

Cabbage splitting
In cabbage, the resumption of rapid growth after a period of slow growth can cause the heads to split, rendering them unmarketable. The risk of splitting increases as heads approach maturity. Rain or irrigating a dry soil is a common trigger for splitting. Uneven maturity resulting from uneven germination and growth, uneven or poor irrigation, insect damage or mechanical damage will increase the risk of splitting, especially if the crop cannot be continually harvested as the plants mature.

Proper irrigation should prevent most splitting.

Splitting can be largely overcome by planting varieties known to resist splitting.

Splitting can also be overcome by harvesting when the crop is mature. So it is important to plant the crop at the proper time. For example, avoid field setting transplants of a storage variety (late season) early in the season as the variety would probably mature before common storages are cool enough. It is best to plant early, mid-season and late season varieties in that order.

Tight spacing in and between rows reduces the risk of splitting.

One method to partially control splitting is to prune the roots by cultivating close to the plants. This approach slows water uptake by the root system. This method is difficult to employ and may result in some mechanical damage if not done carefully.

Harvesting

Cabbage maturity
Cabbage maturity is determined by the firmness and density of the heads and by the size characteristic of that variety. Late storage cabbages should be hard and dense, but the outer head leaves should not be cracking or the head starting to split. Heads of early and mid-season varieties of green cabbage and Savoy cabbage are firm at maturity but yield to moderate pressure when squeezed.

Cauliflower and broccoli maturity
Cauliflower and broccoli maturity should be determined by the firmness and compactness of the heads, rather than by their size. Heads of both should be full, firm and compact. The florets that form the broccoli heads should be tight, not open, and a uniform green or blue-green. Cauliflower curds should not be separated and should be a bright white. Heads must be harvested when they reach this stage.

Both broccoli and cauliflower heads become over-mature very quickly. Hot weather hastens over-maturity. Broccoli florets become loose, the stalks elongate and the yellow flowers start to open. Cauliflower curds separate, and become uneven and "ricey."

Brussels sprouts maturity
Harvest when sprouts are about 2.5 to 5 cm (1 to 2 in.) in diameter. Sprouts may be held on the stalk for storage.

Post-harvest handling and storage

Cole crops should be cooled as quickly as possible after harvest to prevent wilting, discolouration and loss of quality. Cole crops should generally be stored at 0°C (32°F) and more than 95 per cent relative humidity. Only mature, disease-free specimens should be stored. Typically, excess leaves and other material are trimmed or removed to improve airflow in storage.

Broccoli has a storage life of approximately 1 week under optimum storage conditions. Storage life can be increased by packing the broccoli in non-perforated polyethylene bags. Packing broccoli heads in a layer of crushed ice (slush) can accelerate cooling and prolong storage lifespan.

Brussels sprouts have a storage life of 3 to 4 weeks at 0°C (32°F) and a high relative humidity. Sprouts also benefit from storage in polyethylene bags. Sprouts should be left on the stalk during longer term storage to help maintain quality.

Cauliflower is not usually stored. It can, however, be held for up to 2 weeks at 0°C (32°F).

Early cabbage is not generally stored. However, if necessary, it can be held for 3 to 4 weeks. Late cabbage can be successfully stored for 5 to 6 months at 0°C (32°F) and high humidities. Cabbage may be stored in bulk or in tote bins. Pile depth for bulk stored cabbage should not exceed 2 to 3 m (6 to 8 ft.). Adequate ventilation is required. Varieties vary considerably in their ability to retain their green colour during storage.

Lettuce

Varieties/cultivars

Romaine (also called: Cos) types have tall heads with tightly packed, rigid leaves. Outer leaves are darker and less tender than inner leaves. Romaine types tend to be more resistant to bolting (forming a seed head) than other types, and they have good storage potential.

Crisphead (also called: head, iceberg) types have thin, light green leaves packed together to form a tight round or oval head. Crisphead types do best in uniform cool conditions; otherwise, bolting, tip burn and poor flavour may become problems.

Butterhead (also called: buttercrunch, semi-head, Bibb) types have heads that are smaller and looser than the crisphead types. The leaves are tender and have excellent flavour.

Leaf lettuce types have leaves that do not form a tight head. Many different leaf shapes and colours are available, with highly variable flavour. These types mature quickly but tend to bolt and develop tip burn in hot conditions.

Climate and soil requirements

Lettuce is a cool-season crop, growing best at temperatures between 15 and 18°C (60 and 65°F) up to a maximum of 24°C (75°F). Production should be focused on the early and later parts of the season, when cooler conditions prevail. Lettuce will grow in temperatures as low as 7°C (38°F) and can handle light frost, if acclimated.

High temperatures and dry conditions will result in lower yields, poor quality and off flavours. High temperatures can also cause lettuce to bolt. Some types of lettuce are somewhat less sensitive to high temperatures (e.g. romaine).

Planting

Lettuce seed will germinate at soil temperatures over 4°C (39°F) and can be planted early. Germination will be quickest in warmer soils. Lettuce can be direct seeded or transplanted.

Lettuce can be seeded using a range of equipment types. Seed may be raw or pelleted. The amount of seed required will depend on pellet size, percentage germination and spacing required. Plant lettuce seed 1 cm (0.5 in.) deep.

Transplants should be seeded about 4 to 5 weeks before being placed in the field. Well hardened lettuce transplants will withstand spring frosts and can be field set relatively early (late April to mid-May). Either direct seeded or transplanted crops may deteriorate rapidly if exposed to hot weather.

The final plant spacing will vary with the type of lettuce. Leaf and smaller head lettuce types (e.g. butterhead) can be planted with rows 30 cm (12 in.) apart, whereas larger head lettuce types (e.g. crisphead) should be planted with rows as close as 40 cm (16 in.) apart.

Final in-row spacing should be 20 to 30 cm (8 to 12 in.) for leaf and smaller head lettuce types and 30 to 35 cm (12 to 14 in.) for larger head lettuce types. A variety of row configurations can be used, depending on the type of equipment being used.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally broadcast and incorporate the following:

- 55 to 110 kg N/ha (50 to 100 lb. N/ac.)
- 116 to 160 kg P/ha (105 to 145 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

A portion of the required nitrogen may be side-dressed 3 weeks after planting.

Lettuce can exhibit deficiencies in some micronutrients, depending mainly on the soil type. Mineral soils are somewhat less prone to deficiencies. Copper deficiency can sometimes occur in lettuce on very sandy soils. Small amounts of copper may be supplied via foliar sprays if an application is deemed necessary by plant tissue testing. Manganese deficiencies may occur on some organic or heavy soils. Foliar applications can be used to supply manganese if required.

Calcium deficiencies are common in lettuce, mainly due to non-uniform moisture availability. Ensuring that water and nutrient uptake are optimized can reduce calcium deficiencies. The foliar application of calcium chloride or calcium nitrate can help prevent problems in stressed crops. Cultivar selection is probably one of the best tools for managing this problem.

Irrigation

Lettuce is generally considered to be shallow rooted. Lettuce requires a steady, uniform amount of moisture throughout the growing season, from germination onwards.

Insect pest management

Aphids (various species)

Description/life cycle

The lettuce aphid, *Nasonovia ribisnigri*, is not known to occur on the Prairies at this time. Other aphid species occasionally infest lettuce. Aphids tend to colonize inner leaves rather than outer ones.

Damage/symptoms

The presence of aphids and moulted skins may reduce marketability. Aphids may also be the vector (carrier) for some viruses. Excessive aphid feeding may cause wilting.

Control/management

Chemical control is difficult because the outer lettuce leaves protect the aphids.

Aster leafhopper (*Macrosteles quadrilineatus*)

Description/life cycle

The life cycle of this pest is described in Aster Leafhopper in the Carrots section.

Damage/symptoms

Direct feeding damage is of little concern. Vectoring of aster yellows phytoplasma by the leafhoppers is the primary concern. Centre leaves in lettuce show aster yellows symptoms first, typically appearing chlorotic and/or developing improperly. Stunting, twisting and discolouration are also symptoms of aster yellows. Plants are susceptible to aster yellows from the seedling stage to about three-quarters grown.

Control/management

Management of the aster leafhopper in lettuce is similar to that for carrots and celery. Be aware that lettuce is more susceptible to aster yellows than either of those crops, so economic damage thresholds are extremely low.

Disease management

Aster yellows (aster yellows phytoplasma)

Aster yellows symptoms in lettuce
Photo: Manitoba Agriculture, Food and Rural Development

Description/disease cycle
Aster yellows affects a number of different vegetable crops and plants worldwide. The phytoplasma is transmitted by a number of vectors, but the aster leafhopper appears to be the chief vector on the Prairies (see Aster Leafhopper in the Carrots section). The pathogen may be able to overwinter in perennial crops, most notably alfalfa.

Damage/symptoms
The leaves in the centre of the plant may be the first to show symptoms, appearing yellow and distorted. Light brown to pink discolouration of leaf midribs is the best symptom to use for diagnosis. Leaves may be curled, twisted and may appear to be reduced in size. Plants infected early in development will be stunted with twisted yellow leaves. Late infections result in very pale plants with symptoms of tip burn (see Tip Burn in the Lettuce section.

Control/management
There is no way to control the phytoplasma directly. Therefore, the insect vector needs to be managed. Control perennial weeds in and around the planting to reduce leafhopper hosts. Forage legumes, such as alfalfa, that are grown near vegetable crops should be treated with a registered insecticide before cutting or seed harvest.

Sclerotinia drop, lettuce drop (*Sclerotinia sclerotiorum*, *Sclerotinia minor*)

Sclerotinia drop of head lettuce
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man..

Description/disease cycle
Known as white mould in other crops, sclerotinia drop in lettuce is caused by two different species of the fungus *Sclerotinia*. The more common of the two, *Sclerotinia sclerotiorum*, can infect a number of hosts, including many vegetable crops, weed species and canola.

Hardened overwintering structures, known as sclerotia, form on diseased plants and fall to the soil with the decomposition of the host tissue. When there are long periods of moisture, sclerotia can produce mycelium that grow towards and infect the lettuce leaves directly.

Compared to *Sclerotinia minor*, *Sclerotinia sclerotiorum* can be more difficult to manage because it can also produce air-borne spores that can travel for long distances. *Sclerotinia sclerotiorum* may be able to survive for weeks on lettuce leaves, suggesting that lettuce may become infected some time after the spores were deposited on the leaf surface.

Damage/symptoms
The first symptom of sclerotinia drop is the wilting of plants at various stages of maturity, followed by a dropping of the outer leaves of the plant. Dropped leaves remain attached. The pathogen spreads up the centre of the plant.

Other symptoms can be very similar to those caused by grey mould (*Botrytis cinerea*). However, the mycelium of *Sclerotinia sclerotiorum* is white, as opposed to the grey colour of *Botrytis*. Large black sclerotia are usually visible in the mycelium, which can further aid in disease diagnosis.

Control/management
Crop rotation tends to be of little benefit for management of this disease since the sclerotia can survive in the soil for several years and the pathogen can infect a number of different hosts.

Do not apply excess nitrogen as this approach can promote succulent growth, which favours disease development. Irrigation should be managed carefully because wet soil for prolonged periods can promote growth of the pathogens.

Some evidence suggests that broccoli residues can suppress *Sclerotinia minor*, but not *Sclerotinia sclerotiorum*.

Tip burn (nutrient disorder)

Tip burn in lettuce typically caused by calcium deficiency
Photo: Gerald Holmes, Valent USA Corporation, Bugwood.org

Description
Tip burn is a nutrient disorder and is not caused by a pathogen. Deficiencies of calcium in the growing tissues of leaves are the cause. The inner leaves of vegetables that form heads such as lettuce, cabbage and brussels sprouts may all develop this condition.

Damage/symptoms
Tip burn begins as small necrotic areas around the leaf tips. As the infected tissue expands, the edge of the leaf appears brown, and eventually, the entire leaf surface may turn brown. Secondary decay organisms may colonize the infected areas and lead to further rots.

Control/management
Tip burn is the result of an interaction of a number of factors, so managing this disorder can be a challenge. Maintaining soils at high levels of calcium relative to magnesium and potassium may alleviate some of the problems. Reducing nitrogen applications to limit growth, particularly in warm conditions, can be beneficial. Harvesting before crop maturity may also be helpful. Some types of lettuce are less prone to tip burn.

Weed management

As a relatively small plant, lettuce struggles to compete against weeds. Therefore, a high degree of weed control is required throughout the production cycle. Transplants are better able to compete against weeds than a direct-seeded lettuce crop.

Control perennial weeds before planting. Cultural practices such as tillage may be effective for managing between-row weeds. Relatively few selective herbicides are approved for use in lettuce. Lettuce's sensitivity to the residues of many herbicides needs to be considered when planning crop rotations.

Harvesting

The stage at which lettuce is harvested will depend on the type.

Leaf lettuces should be harvested regularly to ensure that harvested leaves are tender with no signs of bolting. Multiple plantings may allow for more than once-over harvesting. Product may be packaged in the field. If doing so, make sure the product is clean and free from debris and other contaminants.

Head type lettuces (Bibb, romaine and iceberg) should be full-sized and firm. Avoid harvesting split or overly mature heads.

Post-harvest handling and storage

Following harvest, lettuce must be cooled as quickly as possible. Grade and trim produce to remove poor quality and damaged product. Some washing may be required before packaging.

Lettuce stores best at 0°C (32°F) and relative humidity greater than 95 per cent. Head type lettuces (Bibb, romaine and iceberg) can be stored satisfactorily for up to 3 weeks if field heat is removed rapidly and low temperatures are rapidly achieved and maintained. Consider the use of plastic bags to prevent moisture loss.

Rhubarb

Varieties/cultivars

A number of different varieties of rhubarb exist, but producers will be limited by what their nursery or plant supplier can supply. Generally, seek out varieties with high vigour, good, intense stalk colour, good flavour and limited seed stalk production. Varieties include German Wine, Canada Red, Mcdonald, etc.

Climate and soil requirements

Rhubarb is a cool-season, perennial plant that can grow in the majority of the climates found on the Prairies. An individual rhubarb plant can be productive for 10 years or longer if maintained properly.

A well drained but moisture-holding soil is required. Avoid waterlogged soils. Lighter soils will produce an earlier crop but will require more frequent irrigation. Rhubarb tolerates a wide range of soil pH.

Fields should be summerfallowed before planting to eliminate perennial weed infestations. The field should be deep ploughed in the summer and the seedbed prepared in advance of planting crowns. The addition of organic matter (e.g. compost, manure, etc.) before planting is recommended to encourage vigorous growth.

Planting

Select plants for propagation in the summer months when they are growing vigorously. Viruses and a range of other pathogens can be carried over in the crowns used to establish rhubarb fields. Therefore, be sure to propagate from the healthiest plants. Select healthy, vigorous 3- or 4-year-old crowns and divide them to obtain 3 or more buds per seed piece.

Planting of crowns can be done early in spring or late in the fall when crowns are dormant. Crowns should be planted 7 to 10 cm (3 to 4 in.) deep and 90 cm (3 ft.) apart in the row. Rows should be 90 to 120 cm (3 to 4 ft.) apart.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Maintain a base level of fertility at approximately the following:

- 165 kg N and P/ha (150 lb. N and P/ac.)
- 330 kg K/ha (300 lb. K/ac.)

Apply an additional 55 kg N/ha (50 lb. N/ac.) after harvest each year.

Irrigation

Rhubarb prefers moist conditions. Apply about 7.5 cm (3 in.) of water (including precipitation) every week to 10 days, particularly during hot summer conditions.

Irrigation can also cool the crop, which may prevent the slowing of growth that occurs when temperatures exceed 27°C (81°F). Irrigation should continue through September, ensuring that plants enter the winter with good moisture.

Insect pest management

Spinach carrion beetle (*Aclypea bituberosa*)

Description/life cycle

Spinach carrion beetle adults are 10 to 12 mm (0.4 to 0.5 in.) in length, flat, oval and black with ridges on the wing covers. Larvae are flattened, being broadest at the head and tapering to the rear.

Adults overwinter in the soil at field margins and ditches. They emerge in spring to lay eggs on leaves. The larvae feed from May to mid-summer. The insects pupate in soil, and the adults emerge to feed before returning to the soil to overwinter.

Other hosts of this pest include cabbage, radish, potato and lettuce.

Damage/symptoms
Adult and larval feeding is most damaging in spring when the plants are small. Feeding damage appears as large holes or ragged edges. Larvae prefer to feed at night but may be seen feeding in the day.

Control/management
Remove weeds from field margins early in the season to reduce adult and larval populations. Insecticidal sprays early in the growing season may be necessary to suppress larvae.

Disease management

Ramularia leaf spot (*Ramularia rhei*)

Characteristic leaf lesions of ramularia leaf spot
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
Ramularia leaf spot disease, while of minor importance, may occur periodically on rhubarb plantings. Rhubarb is the primary host of this pathogen.

Damage/symptoms
Infection of leaves and petioles (leaf stalks) appears initially as red spots, later enlarging to become circular lesions of 1 cm (0.4 in.) and larger. The largest lesions are white to tan and are surrounded by purple-red halos. As conidiospores (asexual fungal spores) are produced, the centres of the lesions appear white. Spotting of the petioles occurs later on.

Control/management
Remove, incorporate and/or destroy all crop residues after harvest and at the end of the season. Remove stalks with spotted leaves first to reduce the amount of infection and disease.

Apply fertilizers early in the season to encourage rapid, healthy growth.

Red leaf, bacterial soft rot, crown rot (*Erwinia rhapontici*)

Rotten rhubarb crown associated with red leaf
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Description/disease cycle
These above-named infections are likely associated with wounds because damage caused by root-feeding insects and stem and bulb nematodes provides possible entry points for the pathogen.

Damage/symptoms
The main symptoms of these pathogens are terminal bud decay as well as brown discolouration and soft rot of the central pith, eventually developing a cavity within the crown.

The loss of the terminal bud may lead to the growth of weak side shoots, which often wilt and rot. During periods of wet weather, older leaves can rot. Red leaves are often apparent on diseased plants.

Control/management
Plant disease-free crowns. Rogue (remove/cull) diseased plants and destroy them. Do not plant new crowns into areas where diseased crowns have been removed.

Keep stands vigorous. Avoid unnecessary injury to the crowns during cultivation and harvesting operations. Do not allow aphids and other foliar-feeding insects to reach high numbers in rhubarb plantings.

Harvest healthy plants first and diseased plants last to avoid spreading the red leaf pathogen on harvest equipment.

Weed management

Plant into a clean field free of perennial weeds. Few herbicides are registered for use in rhubarb.

Other requirements

To maintain good plant vigour, cut and remove flower stalks while they are still small.

Harvest

Stalks should not be harvested during the first year of growth. A single harvest may take place in the second season. After plants are fully established, two major harvests can take place each year without affecting the next year's crop.

Harvest should take place in early June and about mid-July, depending on the geographical location. Stalks should be pulled, not cut. A few leaves should be left on each crown after harvest. If possible, irrigate plants immediately after harvest to promote regrowth.

Quality rhubarb stalks are crisp and fresh with good colour and free from damage, wilting and desiccation.

Post-harvest handling and storage

Rhubarb stalks (petioles) should be trimmed to remove leaves. The stalks may be washed to remove any dirt or debris. Stalks may be bundled or sold loose.

Harvested rhubarb should be cooled as quickly as possible to 0°C (32°F) and may be stored for 2 to 4 weeks at 0°C (32°F) and greater than 95 per cent humidity.

Spinach

Varieties/cultivars

Varieties tend to be used for 4 to 5 years and are then replaced. Some varieties (such as Tyee) have been used for a number of years. Choose types that hold their quality (i.e. tenderness, flavour, etc.) for a long period and through different weather conditions.

Climate and soil requirements

Spinach is a cool-season crop, growing best at 15 to 18°C (60 to 65°F) and tolerating temperatures up to 24°C (75°F). Spinach will grow in temperatures as low as 4°C (39°F).

Spinach has a tendency to bolt (produce seed heads) when grown under long days or warm conditions. Therefore, spinach should be produced in the spring, early summer or fall. Selecting for bolting-resistant, heat-tolerant varieties will allow production through the middle of the summer (longer days).

Spinach will grow in most soils. Sandy or sandy loam soils work best with early or late production, as they tend to warm quickly. Soil pH should be between 6.5 and 7.5 for ideal growth.

Planting

Spinach can be sown in early spring, as soon as soils can be worked, then at two-week intervals through until late summer to ensure a steady supply. Fall crops may be overwintered or crops may be fall-seeded, for very early spring production.

Spinach will germinate at soil temperatures as low as 4°C (39°F), with optimum germination between 10 and 16°C (50 and 61°F). Seed will germinate at higher temperatures, but performance may vary depending on the cultivar.

Spinach can be seeded at a depth of 1.25 to 2.5 cm (0.5 to 1 in.), with rows spaced 30 cm (12 in.) apart and plants spaced 5 to 10 cm (2 to 4 in.) apart within the row. Approximately 17 kg of seed is required per hectare (15 lb./ac.).

Fertilizer

Fertilizer applications should ALWAYS be made based on annual soil tests. Generally, apply the following to mineral soils:

- 88 to 110 kg N/ha (80 to 100 lb. N/ac.)
- 77 to 116 kg P/ha (70 to 105 lb. P/ac.)
- 50 to 99 kg K/ha (45 to 90 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

Adjust application timing and nutrient quantities depending on soil types, cropping plans and seasonal precipitation.

Boron deficiencies can occur in spinach in hot, dry weather. However, applications of boron are not necessarily effective, and over-application can have very negative effects. Foliar application of boron to young plants may offer some remedy for identified boron deficiencies.

Magnesium deficiencies can occur in some regions. Apply dolomitic lime to soils with pH below 6.0, or apply magnesium-containing fertilizers either to the soil or as foliar sprays.

Irrigation

Irrigation requirements for spinach are similar to those for lettuce and other leafy vegetables. Spinach is shallow-rooted and should not be allowed to dry out. Moisture stress can reduce quality.

Other requirements

The consumption of foods containing excessive concentrations of nitrates is a potential health concern. Spinach and other leafy vegetables have the potential to accumulate significant quantities of nitrates, particularly if grown under cool conditions in nitrogen-rich soils.

For this reason, take care to match nitrogen fertilizer applications to the actual crop requirements, especially as harvest time approaches. Nitrate levels are difficult to predict as they can be influenced by field conditions, cultivar and even the time of day the crop is harvested.

In recent years, there have been occasional food safety scares related to fresh lettuce and spinach, primarily due to concerns about contamination with *E. coli* in some areas. Mitigate the risk of contamination by implementing effective on-farm food safety processes and procedures. See the Food Safety section in the Business Management chapter for information.

Insect pest management

Insect pests are similar to those in lettuce (see Insect Pest Management in the Lettuce section).

Disease management

Downy mildew (*Peronospora farinosa* f. sp. *spinaciae*)

Description/disease cycle

Downy mildew is considered to be the most important disease of spinach in many areas. On the Prairies, this disease is not as common, unless spinach is under excessive irrigation.

The pathogen that causes downy mildew in spinach also infects *Chenopodium* plant species, such as lamb's quarters. The pathogen survives winter as mycelium.

Highly vigorous spinach plants combined with wet leaf surfaces and temperatures from 2 to 30°C (36 to 86°F) (optimal is 9°C; 48°F) are required for downy mildew spore germination and leaf infection. Due to the dense canopy of spinach, even limited moisture can create an ideal environment for infection and disease development. Lesion development is enhanced at temperatures between 15 and 25°C (59 and 77°F).

After about a week, with relative humidity between 70 and 90 per cent, spores are produced. Spores are dispersed by winds and splash-dispersed by water.

With favourable temperatures and suitably wet leaf surfaces, downy mildew has the potential to progress very rapidly, leading to extensive losses.

Damage/symptoms
Disease symptoms appear initially as pale green to pale yellow, irregularly shaped lesions on cotyledons and true leaves. With time, the lesions become bright yellow and increase in size. If conditions become dry, the lesions become tan and dry. With persistently wet conditions, the tissue may become soft and necrotic.

Sporulation usually occurs underneath the yellow spots, where the underside is purple. Under severe disease conditions, spores may be produced on the upper surface of the leaves.

When disease pressure is high, leaves may be curled and distorted. This blighted effect, which is attributed to numerous infection sites, will result in leaf collapse.

Control/management
Once established, downy mildew is very difficult to manage. When possible, plant resistant cultivars. Consider using registered foliar fungicides. If using these fungicides, be sure to achieve good coverage of the entire plant.

Rotations of 3 years with non-host crops, such as cereals, may help reduce disease pressure. Control *Chenopodium* weeds because these weeds can enable the pathogen to survive in years when spinach is not grown.

Weed management

As a relatively small plant, spinach struggles to compete against weeds. Therefore, a high degree of weed control is required throughout the production cycle. Control perennial weeds before planting. Cultural practices such as tillage may be effective for managing between-row weeds.

Relatively few selective herbicides are approved for use in spinach. The sensitivity of the crop to the residues of many herbicides needs to be considered when planning crop rotations.

Harvesting

Similar to leaf lettuce, spinach should be harvested when leaves are tender and not tough. Some varieties have a longer harvest period than others. Flavour tends to deteriorate as plants age, especially if the plants begin to bolt. Quality leaves are dark green, turgid (not wilted), free from damage, with uniform and even shape.

Leaves may be packaged directly into bags in the field, provided the leaves are clean.

Post-harvest handling and storage

Cool leaves as soon as possible to maintain quality. Grade to remove any discoloured, damaged or poor quality leaves before packaging.

Some washing may be required. Washing must be done carefully to avoid damaging the leaves. Disinfect the wash water regularly to prevent the spread of bacterial diseases.

Spinach is not typically stored for any length of time. However, cooling to 0 to 2°C (32 to 36°F) and maintaining greater than 95 per cent humidity may allow spinach to be stored for perhaps 7 to 10 days.

Fruiting vegetables

Beans (succulent)

Varieties/cultivars

Snap beans and **bush beans** are standard succulent garden beans that grow either as a bush or vine plant. They are available in a range of colours, with the pods harvested when tender and before the development or maturation of the seed.

Filet beans are thinner and shorter than standard snap or bush beans and are not just an ordinary snap bean picked while still immature. Classic French filet beans had a string and needed breeding to be harvested young. Recent developments in breeding have eliminated the string in most varieties of filet bean.

Broad beans (also called: fava beans, horse beans) are large, edible flat green beans that are typically eaten as immature seeds without the pod. The young leaves of the plant can also be eaten raw or cooked like spinach.

Climate and soil requirements

Beans are generally considered a warm-season crop, growing best between 16 and 24°C (60 and 75°F) and tolerating temperatures up to 27°C (80°F). Beans are sensitive to cool soil conditions and frost at all stages of crop growth.

Beans can be grown on a range of soil types, provided the soil is well drained.

Planting

Snap and filet beans may suffer from extensive seed rot if planted into soil colder than 15°C (59°F). Broad beans can be planted into cooler soil than snap or dry beans. Good emergence can be expected when the soil temperature is above 10°C (50°F). Bean seeds crack easily during handling and seeding, so they should be treated with care.

Plant bean seeds about 3 to 5 cm (1.5 to 2 in.) deep.

Snap beans are normally grown in rows 60 to 90 cm (24 to 36 in.) apart, depending on the equipment available. Seed is placed 3 to 5 cm (1.5 to 2 in.) apart in the row, with a target population of 20 to 26 plants/m (6 to 8 plants/ft.). About 50 to 88 kg/ha (45 to 80 lb./ac.) of seed are required, depending on the planting density, variety and seed size.

Broad beans are grown in rows 90 to 100 cm (36 to 40 in.) apart with about 7 to 10 cm (3 to 4 in.) between plants. About 100 kg of seed per 100 metres of row (65 lb./100 ft. of row) or about 169 kg/ha (154 lb./ac.) are required.

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Beans are legumes and have the ability to fix nitrogen from the air provided the necessary nitrogen-fixing soil organisms are present. All bean seed should be treated with a nitrogen-fixing bacterial inoculant. Despite the ability of beans to fix nitrogen, producers will still generally see a positive yield response to applying fertilizer N to beans.

Generally, broadcast and incorporate the following before planting:

- 28 to 39 kg N/ha (25 to 35 lb. N/ac.)
- 121 to 160 kg P/ha (110 to 145 lb. P/ac.)
- 33 to 66 kg K/ha (30 to 60 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

If side-banding, reduce rates of phosphorus and potassium to one-fifth and one-half, respectively. A small amount of the required nitrogen (2.2 to 3.3 kg N/ha; 2 to 3 lb. N/ac.) and phosphorus (11 to 13 kg P/ha; 10 to 12 lb. P/ac.) can be applied with the seed at planting.

Beans should not be grown on land where boron was applied in the previous season because bean crops are sensitive to boron toxicity.

Foliar applications of manganese may be required for beans on soils with a pH above 6.5, with treatments based on tissue tests. Soil applications of manganese are not recommended.

Irrigation

Beans require 25 to 38 mm (1 to 1.5 in.) of water per week during peak growth. Critical moisture periods are during flowering and pod set. However, uniform moisture is recommended from flowering through to harvest.

Insect pest management

Seed corn maggot (*Delia platura*)

Seed corn maggot larvae emerging from stem
Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Seed corn maggot damaged bean seedling
Photo: Howard F. Schwartz, Colorado State University, Bugwood.org

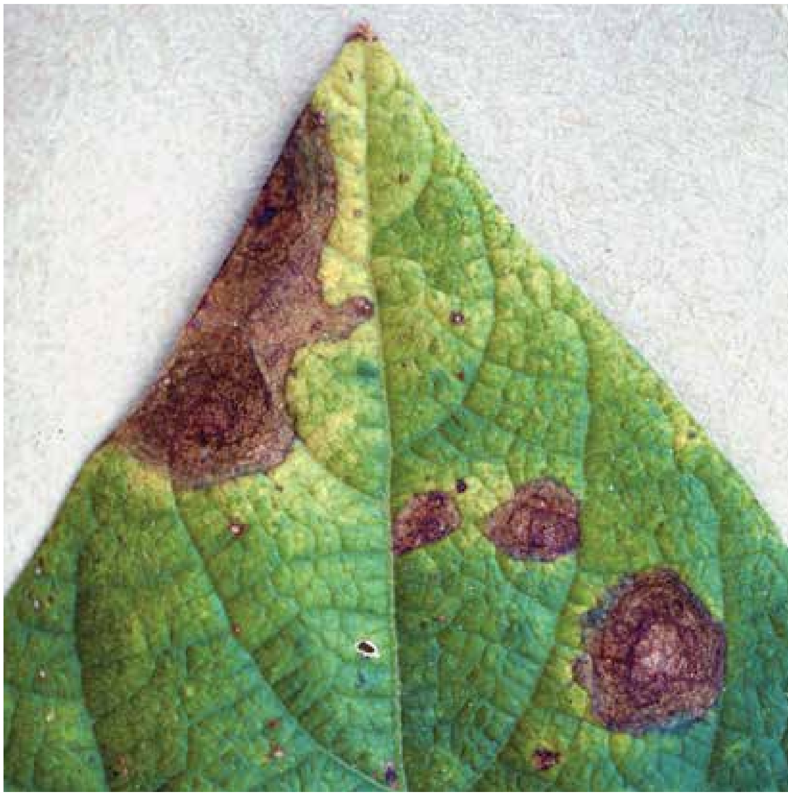
Description/life cycle
Adult flies of the seed corn maggot are similar in appearance to house flies. Overwintering as a pupa in the soil, the adult emerges in spring and lays eggs near plants or seeds in moist soils with high organic matter or abundant decaying vegetation. Larvae are white, legless and reach a length of 5 mm (0.2 in.) at maturity.

Damage/symptoms
Larvae feed readily on developing seedlings, cotyledons and root collars. Damaged plants often wilt and die before emergence, giving the appearance of poor emergence and, potentially, indicating a need for subsequent reseeding.

Control/management
Damage is usually localized, and the maggots seem to prefer to feed on decaying organic matter, so timing of damaging outbreaks may be a bit of a matter of luck. Cultivation to destroy rotting vegetation is helpful because the rotting vegetation attracts ovipositing (egg laying) females. Seed treatments are the only practical course of chemical management.

Disease management

Alternaria leaf and pod spot (*Alternaria alternata*)



Alternaria leaf spot, caused by *Alternaria alternata*
Photo: Courtesy S. K. Mohan; Reproduced, by permission, from Schwartz, H. F., Steadman, J. R., Hall, R. and Forster, R. L. 2005. Compendium of Bean Diseases, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/disease cycle
Alternaria leaf and pod spot is a common disease of maturing bean plants, with crop losses largely due to discoloured seeds and pods.

Alternaria alternata is a common fungus found in association with a number of plant species. It survives on crop and weed debris and can grow as an epiphyte (surviving only on surfaces). All above ground portions of the bean plant are susceptible.

Prolonged surface wetness of at least 24 hours is required for spores to germinate and infect the bean tissues. Spores are dispersed by rain and sprinkler irrigation. The fungus attacks mature and senescent tissue later in the season. Plants may take on a brown to grey cast when harvesting is delayed due to wet conditions.

This disease tends to be more prevalent on early maturing beans. Infestation levels of this pathogen have been reported to be high (94 per cent) even on non-discoloured seeds.

Damage/symptoms
Leaf spot typically occurs on the older trifoliate leaves of beans. Initially, small flecks appear on leaves and pods. On leaves, the small spots appear as a series of concentric rings like a target. A yellow halo often surrounds the lesion. The spotting tends to occur between the major leaf veins.

As they grow larger, the lesions become more angular. Lesions can then coalesce, causing larger areas of the leaf to die back. If dry conditions persist, the lesions may begin to tear and fall out, leaving a shot hole appearance.

Pod spotting may appear in the form of red-grey-brown flecking over the surface. With the onset of wet conditions, pods may appear grey and mouldy.

Control/management
Control measures are seldom warranted in areas where dry conditions are common near bean maturity. If this disease is a persistent problem in an area, consider using wider row spacing (lower plant populations), choosing resistant cultivars and lengthening crop rotations between bean crops.

Bacterial blights:

Common blight (*Xanthomonas campestris* pvr. *phaseoli*)

Description/disease cycle
Common blight-affected foliage and pods are a major problem anywhere beans are produced. Yield and seed quality can be markedly reduced.

Contaminated seeds, infected crop residue, epiphytic (surface) growth on non-host species and weeds are all potential sources of the bacterium. If the pathogen is seed-borne, the initial occurrence of the disease appears randomly throughout the crop, depending on the level of infection in the seed.

The bacterium can be spread via wind-blown soil, plant debris, irrigation water, people, machinery, animals, insects and contact between wet leaves. Temperatures between 28 and 32°C (82 and 90°F) and high humidity can lead to extensive losses.

Damage/symptoms
Common blight symptoms usually occur just before flower development, when small water-soaked spots appear on leaves. Spots enlarge and become necrotic, with an area of bright yellow tissue bordering the spots. The affected areas lose turgidity, and as lesions coalesce, the necrotic areas appear burned and disintegrate.

Bright yellow bordered lesions indicative of common blight
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Halo blight infection with wide, tell-tale yellow-green lesions
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Pods may develop round, sunken, water-soaked spots. The spots are often surrounded by a red edge. High relative humidity can promote bacterial oozing on pods.

Infected seeds have yellow or brown spots on the seed coat. Severely infected seeds shrivel.

Control/management
The use of healthy, pathogen-free seed is critical. Use cultivars with at least partial resistance, if possible.

Once the disease is established in a crop, management options are limited to reducing irrigation and limiting the entry of people or machinery into the field (to avoid splashing water and subsequent movement of the pathogen).

A minimum rotation of 2 years between bean crops will help prevent carry-over of infection from one crop to the next. Weeds and volunteer beans should be destroyed. Registered fungicides may be applied before symptom appearance.

Halo blight (*Pseudomonas syringae* pvr. *phaseolicola*)

Description/disease cycle
Halo blight is a common foliar disease anywhere beans are grown, especially in areas with moderate temperatures and multiple sources of the bacterium. This disease is considered to be a cool-temperature disease as development is optimal at 18 to 22°C (64 to 72°F).

This disease can come from a number of sources including contaminated seed and infested plant residue. Contaminated seeds can possess large amounts of the pathogen before symptoms become visible. The bacterium enters the plant via natural openings, such as stomates or hydathodes (openings at the end of leaf tips), or through wounds when very humid conditions exist. Blossoms, pods and stem tissues can all be colonized.

The bacterium can grow as an epiphyte (grows on other plants) on both resistant and susceptible cultivars. Increasing in numbers but causing no damage, the bacterium can reside on leaves until splashing rains, overhead irrigation, dew or direct contact with clean leaves allows for dispersal. Personnel and machinery moving through wet fields can also spread the pathogen.

Damage/symptoms

Initially, leaf symptoms appear on the first and second trifoliate leaves as water-soaked spots on the lower leaf surface. These spots rapidly become angular in shape and necrotic/brown. Leaves that are infected while expanding may appear distorted. A yellow-green halo may appear around the spots, which is the result of the bacterium's production of a toxin at temperatures of 18 to 23°C (64 to 73°F).

Symptoms are not expressed at higher temperatures, and above 23°C (73°F), the halo becomes less noticeable or absent. About 1 week after infection, bacteria ooze from cavities to give lesions a greasy, water-soaked appearance.

Stems and pods develop red or brown lesions that appear water-soaked. As pods mature, lesions turn yellow to tan. Pod lesions appear sunken with red margins, though they may remain green and show a crusty ooze on the surface. Seeds may be shrivelled or discoloured.

Elongated areas of infection may appear in the field; these areas approximate the direction of the prevailing winds.

Control/management

At planting time, clean and then disinfect equipment frequently. Use 10 per cent bleach or quaternary ammonium as disinfectants.

Plant only disease-free seed. Some seed-testing companies offer DNA-based tests that can detect the presence of the pathogen on symptomless seed.

Use resistant cultivars, if available.

Use furrow irrigation, if possible. Avoid working in fields when plant foliage is wet. Plough crop debris under promptly, and follow a three-year rotation. Do not apply bean debris in manure to fields intended for beans before planting. Eliminate weeds and volunteer beans. In smaller scale operations, remove individual diseased plants.

Well timed applications of registered fungicides may reduce populations of bacteria, decreasing the likelihood of severe outbreaks.

Fusarium root rot, dry root rot (*Fusarium solani* f. sp. *phaseoli*)

Description/disease cycle

Fusarium root rot or dry root rot is a common root disease of beans. While entire plants may be killed, the general reduction in productivity of large numbers of plants causes yield and economic loss. Essentially, plants do not achieve the potential yields normally anticipated in a production area.

Fusarium solani can be present in many soils, but beans (and potentially peas and crops in the *Vicia* genus, such as vetches and broad beans) normally require some sort of additional stress for severe losses to occur. Environmental stresses such as drought, flooding and soil compaction can all lead to oxygen stress in roots, which can predispose plants to infection.

While cultivars resistant to root rot do exist, even oxygen deprivation for as short a period as 24 hours can lead to severe damage. In areas prone to flooding, this disease can be a persistent problem. Other bean diseases, such as rhizoctonia root rot and pythium root rot, may also be present, which can place further stress on the crop.

The fungus is soil-borne and can build up over years with short crop rotations. Thick-walled resting spores known as chlamydospores enable the pathogen to survive in the soil for long periods.

Compounds derived from bean roots trigger the germination of the spores and subsequent growth of the fungus toward the root hairs. The fungus penetrates through wounds or stomates and proceeds to grow through the roots. In wet conditions, air-borne spores may emerge from the plants via stomates. As the tissues continue to break down, the fungus converts to the hardened resting spore state and remains in the soil or crop debris.

As this fungus can germinate and continue to reproduce on plants and weeds that do not succumb to infection, it is possible for this fungus to survive in soil for decades. Blowing soil and water movement can transport and introduce the fungus to new areas.

Generally, the disease is severe in cool and moist soils. However, yield reductions can be significant with the onset of drought conditions.

Damage/symptoms

Initially, narrow red to brown streaks occur on hypocotyls (stems of germinating seedlings) and taproots in week-old seedlings. As the disease progresses, the cortex of older portions of the root appears streaked, and tissues begin to turn brown. If the root system is not restricted or hindered in any way, pod and seed production may appear normal.

Large numbers of adventitious (occurring in other than the usual location) roots develop from the hypocotyls in response to the damaged taproot and will grow near the surface.

The disease can lead to stunting and force the plant to rely on the adventitious roots for survival. The primary leaves of such plants may turn yellow prematurely or may be pale green.

At a field level, an uneven canopy may be observed, as plants can be in various states of stunting.

Fusarium root rot infected bean seedlings; note brown streaking of hypocotyl tissue
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

If fusarium root rot is suspected, examine the vascular system near the stem base for black to red streaking. Other fusarium diseases (e.g. fusarium wilt) also stain the vascular system, so it may be necessary to have a sample lab tested to determine the exact fusarium species involved.

Control/management

Practices that promote fertile, well-aerated soil are key to managing this disease. Avoid soil compaction, and use deep tillage to break up or loosen sub-layers of soil.

In fields where root rot is known to be a problem, cultivate and fertilize to obtain maximum growth. Plough down crop residue promptly after harvest.

Most of the common bean varieties available on the Prairies are intermediate in tolerance, although cultivars with high tolerance have been reported. Use cultivars that have some degree of tolerance, if available. Plant clean, vigorous seed. Seed treatments may provide some benefit, but may not offer any protection once the root system develops.

Limited chemical controls are available. Once the pathogen is established in the field, very long rotations may be necessary, with up to 10 years of non-bean and non-pea production. Cereals, beets, onions or corn are good options. Green manures, such as red clover and alfalfa, have shown some promise in managing this disease.

Grey mould (*Botrytis cinerea*)

Description/disease cycle

Botrytis cinerea is a common pathogen capable of causing disease on a wide range of plants. All plant parts can develop the disease.

The first infection sites are typically dying flower tissues and other tissues that are aging and senescing. The most commonly infected plant parts are damaged or dying cotyledons, followed by stems and leaves and plant parts with mechanical or pest damage.

The development of this disease is favoured by high humidity. Spores are airborne. Infections require water. Temperatures from 10 to 25°C (50 to 77°F) are suitable for infection to develop. Sporulation can occur rapidly on diseased tissues, in as little as 2 to 3 days after infection.

Infected stems, pods and bulky tissues develop sclerotia that can overwinter both in the soil and in crop debris. Sclerotia in the soil can produce large quantities of spores for long periods, leading to multiple infections throughout the year under suitable conditions.

Damage/symptoms
Generally, the first indications of a disease outbreak appear on tissues damaged by frosts, hail, wind, sandblasting or machinery. On leaves, lesions are grey to tan with a defined shape. A yellow margin may be visible. On stems and petioles, long brown streaks appear. On pods, the symptoms initially appear as water-soaked lesions and later become sunken depressions.

As infected tissues dry up, the grey furry mould appears. Clouds of spores are produced on the infected tissue and are dispersed through the air.

The fungus can penetrate the pod via wet areas where a fallen petal adheres to the pod. Infected petals may also get trapped in the leaf axils. If grey mould develops, girdling of the stem at the leaf node may occur, and the rest of the plant will collapse.

Control/management
Maintain air circulation through the plant canopy. Ensure good weed control, and plant rows perpendicular to prevailing winds. Do not over-fertilize with nitrogen so as to avoid dense, lush growth. Avoid long periods of overhead irrigation, particularly during flowering.

Plough under crop debris, as sclerotia can overwinter in debris and soil. Consider the use of more tolerant cultivars, if available. The application of registered fungicides may be an option, but the level of control may not be economical in beans unless the fungicide is applied before the disease becomes established in the crop. Hand-harvested crops should be sorted to avoid pod-to-pod contact with diseased tissue.

White mould, stem and pod rot (*Sclerotinia sclerotiorum*)

Description/disease cycle
White mould can be found anywhere beans are grown. This disease can be troublesome in areas where other host crops are grown in close rotation. Many vegetable crops are susceptible to *Sclerotinia sclerotiorum*, as are canola, sunflowers and weed species.

The disease can develop at temperatures ranging from 5 to 30°C (41 to 86°F), with 20 to 25°C (68 to 77°F) being optimal in beans for infection of ascospores (spores specific to fungi). Mycelium

Botrytis grey mould mycelium present on bean fruit
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Beans infected with *Sclerotinia* with fruiting bodies (sclerotia) present
R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

can grow from plant to plant if an infested plant comes in contact with another plant.

Sclerotia from previous infected crops overwinter in soils and crop debris. The sclerotia can potentially survive for multiple seasons, especially if dry conditions have been prevalent.

Sclerotia can produce trumpet-like structures known as apothecia after exposure to moist, cool (4°C; 39°F) or freezing conditions. Once developed, apothecia can release air-borne ascospores over a 5- to 10-day period. Ascospores require moisture and a nutrient source, such as a petal or senescing tissue, to germinate and infect the underlying host tissue.

Damage/symptoms

Infection usually occurs from early to mid-summer after weather conditions have been warm and wet. At the field level, individual or small groups of plants may be infected within a field.

Infected flowers have a cotton-like appearance as mycelium covers the surface. Lesions are initially small and round with a dark, water-soaked appearance. As the lesions increase in size, they may eventually consume entire leaves, stems and pods. Diseased stems may collapse into a watery soft rot.

The affected tissues dry out and appear light tan to white. Infected stems and pods may develop thick areas of mycelium that form the basis of new sclerotia. Entire plants may be killed as stem tissue is destroyed and sclerotia are produced.

Control/management

Rotations of 4 to 5 years with non-host crops can help reduce inoculum levels. Beets, onions, spinach, corn, cereals or other grasses are good options. However, the pathogen's broad host range and the longevity of sclerotia can make it difficult to reduce the amount of inoculum.

Avoid dense foliage by restricting levels of soil moisture and nitrogen. The reduction of canopy density by using lower seeding rates may be helpful. Planting rows parallel to the prevailing wind can improve airflow through the canopy. Keep above ground foliage as dry as possible. Do not sprinkle irrigate in late afternoon or evening. Use drip irrigation, if possible.

Harvest as soon as beans are mature, and follow with rapid cooling and storage of healthy pods at 7 to 10°C (45 to 50°F).

The application of registered fungicides can help if they are used in conjunction with other practices. If white mould is expected, a preventative application is recommended.

Weed management

Bean plants are decent competitors once they are established. If the crop can be kept weed-free for the first 6 weeks, the effect of competition should be minimal.

The canopy is well designed for inter-row tillage when young, but once plants begin to sprawl, tillage is no longer an option.

Control perennial weeds before planting. Chemical controls are available. Follow label instructions regarding rate and application timing. Consider the effect of applied herbicides when doing rotation planning.

Harvesting

Snap beans are harvested when pods and seeds are young and tender. Pods should be smooth and fairly straight, with few or no bumps from seeds within. Pods should be turgid and should make an audible snapping sound when broken. Pods should be brightly coloured and fresh. Over-mature pods will be stringy and tough, with large, developed seeds.

Beans require harvesting regularly. Typically, pods are ready for harvesting within 8 to 10 days of flowering, although the time to harvest varies depending on weather conditions and the cultivar. Filet and broad beans will take a longer time to reach maturity.

Post-harvest handling and storage

Snap beans can be stored for 8 to 12 days if they are cooled immediately after harvest and held at 5 to 7°C (41 to 45°F) and 90 to 95 per cent humidity. Beans are subject to chilling injury if stored at temperatures below 5°C (41°F). Beans should NOT be top-iced but do respond well to hydro-cooling.

Corn (sweet)

Varieties/cultivars

Corn cultivars are classified based on their kernel characteristics.

Standard (*su*) sweet corn: The original sweet corn (*su*) arose as a mutation of standard field corn. The mutation caused the kernels of the sweet corn to accumulate more sugar than standard field corn.

The *su* types show good tolerance of cool soil at planting and are often quicker to mature than other types of sweet corn. Conversion of the kernel sugars into starch occurs rapidly after harvest, so the post-harvest lifespan of *su* cultivars is limited. Relatively few new *su* cultivars are being released as the market has shifted to higher quality sugar enhanced (*se*) and supersweet (*sh2*) types.

Sugar enhanced (*se*) sweet corn: Sugar enhanced (*se*) sweet corn kernels have a higher sugar content than standard sweet (*su*) types, and the rate of conversion of these sugars to starch after harvest is slower. These two factors improve the post-harvest quality of the *se* types relative to the *su* types.

Kernels of *se* types are more tender with higher moisture content than supersweet (*sh2*) types. The *se* types also have greater tolerance of cool, wet soil conditions at planting than the *sh2* types. There is no need to isolate the *se* types from *su* corn during crop production, but they should be isolated from *sh2* types; otherwise, the quality of the *sh2* types will be compromised by pollen from the other types.

Supersweet (*sh2*) corn: The shrunken (*sh2*) mutation results in exceptionally high kernel sugar content (up to 16 per cent) and very slow conversion of these sugars to starch after harvest. Consequently, supersweet types hold their quality for extended periods after harvest, which is a desirable characteristic for corn destined for the retail market system.

The *sh2* types are typically planted later than *su* and *se* types as the small *sh2* seed is sensitive to cool, wet soil conditions. Some consumers find the kernels of *sh2* corn to be tough. The *sh2* types must be isolated from field corn and *su* and *se* types to preserve the desirable *sh2* qualities.

Augmented (*shq*) supersweet corn: In this newly developed type of corn, every kernel has the *sh2* gene, resulting in a high sugar content and slow conversion of these sugars to starch. However, some of the kernels also have traits from *se* and *su* types, leading to tender, moist kernels and superior flavour. The augmented supersweet types must be isolated from *su* and *se* types of sweet corn.

Synergistic sweet corn: Cobs of synergistic corn cultivars feature a mixture of *sh2*, *se* and *su* kernels, with the ratio of each kernel type varying from cultivar to cultivar. This mixture of *se*, *su* and *sh2* kernels is designed to capture the individual strengths of each type of corn within a single cultivar. Synergistic types of sweet corn must be isolated from *sh2* cultivars; otherwise, the quality of the *sh2* types will be compromised.

For more detailed information on isolation requirements, see the Other Requirements section in this Corn section.

Climate and soil requirements

Sweet corn requires significant lengths of time to mature, although the time requirement varies between types and cultivars. Corn grows best at temperatures between 15 and 24°C (60 and 75°F) and tolerates temperatures up to 35°C (95°F). The base temperature for corn is 10°C (50°F).

Corn can grow on a range of soil types, although soil types can have a significant influence on spring warming and the growth rate of the different types of corn. Corn should be grown on well drained soils.

Planting

To ensure a continued supply of corn for the fresh market, plant several varieties with different maturity dates. Corn should be planted as early as possible; however, corn does not germinate below 10°C (50°F). Emerged corn will withstand frost until it reaches about 10 cm (4 in.) in height because the growing tip is below the soil until that stage.

Plant corn seed into moisture and about 3 to 7.5 cm (1.5 to 3 in.) deep. Seeding rates vary from 4.4 to 7 kg/ha (10 to 15 lb./ac.) depending on seed size. Try to establish stands of 49,400 to 54,340 plants/ha (20,000 to 22,000 plants/ac.). However, lower plant density stands (e.g. 39,400 to 44,400 plants/ha; 16,000 to 18,000 plants/acre) can be used for early market crops.

Row spacing can be from 55 to 105 cm (22 to 42 in.). The spacing will vary depending on the type of equipment and the type of sweet corn. In-row spacing should be 15 to 35 cm (6 to 14 in.).

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Generally, apply the following:

- 149 kg N/ha (135 lb. N/ac.) (depending on preceding crops)
- 28 to 44 kg P/ha (25 to 40 lb. P/ac.)
- up to 110 kg K/ha (100 lb. K/ac.)
- 22 kg S/ha (20 lb. S/ac.)

Fertilizers can be applied in a number of different split application combinations (pre-planting, at-planting banded, post-emergent side-dressing). P and K must be applied at or before planting, whereas N can be applied pre- or post-planting.

At planting, banded fertilizers can be placed 5 cm (2 in.) below and to the side of the seed, with banded amounts of N and P not exceeding 118 kg/ha (107 lb./ac.). If fertilizers are banded with the seed, reduce the amount of nitrogen and phosphorus to no more than 8.8 kg/ha (8 lb./ac.), and apply the remainder pre-planting or as a side-dressing.

Some of the applied nitrogen should be side-dressed when corn is 15 to 30 cm (6 to 12 in.) high.

Irrigation

Corn has a fairly high moisture demand, using up to 6 mm (0.24 in.) per day during peak use periods and up to 510 mm (20 in.) of water (including precipitation) in a season. Critical moisture periods are during tasseling, pollination and ear filling.

Insect pest management

Corn earworm (*Helicoverpa zea*)

Corn earworm larvae on damaged corn cob
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Description/life cycle

The corn earworm is a migratory pest in the Prairie provinces, so populations vary from year to year. Typically a late-season pest, eggs are laid singly on the silks and hatch within 3 days.

Larvae feed on the silks and then enter the ear, feeding from the tip first. Larvae feed for about a month then drop to the ground to pupate.

Larvae are variable in colouration with the body being brown, green, pink, yellow or black. The head capsule is usually orange or light brown with a white net-like pattern. A single broad, dark band is usually on each side above the spiracles (breathing holes), with a light yellow or white band below the spiracles. The presence of spines on the body distinguishes this pest from the fall armyworm.

Damage/symptoms
Damage occurs to the silks and the developing cobs. Yield loss comes from the loss of kernels and from contamination of the cobs by the presence of earworms.

Control/management
Due to the lateness of the arrival of this migratory pest, it is seldom picked up in scouting. The infrequency of its arrival in Canada also means it is often overlooked.

For insecticide application to be effective, the pest must be recognized before larvae enter the corn ears. Scouting is best accomplished at silking. Control products must be directed specifically so that they come into contact with the silks.

Corn leaf aphid (*Rhopalosiphum maidis*)

Description/life cycle
A migratory pest, the corn leaf aphid typically arrives on air currents later in the season. All corn leaf aphids are female and give birth to live young without mating. Populations tend to be highest in dry years. The aphids are greenish-blue to black and usually occur on the tassels and axils of the upper leaves.

Damage/symptoms
Direct feeding damage in the Prairies is usually fairly minimal. However, the plant may be dwarfed, whorl leaves may become desiccated, and the tassels and silks may be covered with honeydew exudate that can lead to mould formation on the affected plant parts. The honeydew also affects pollination. The presence of aphids, honeydew and mould may render sweet corn unsuitable for sale.

Control/management
Treatment with insecticides is rarely justified to preserve yield. Consumers of fresh market corn may not be pleased with the presence of abundant aphids in the leaves of fresh market sweet corn.

European corn borer (*Ostrinia nubilalis*)

Egg masses of European corn borer
Photo: Frank Peairs, Colorado State University, Bugwood.org

European corn borer larvae emerging from stem
Photo: Manitoba Agriculture, Food and Rural Development

European corn borers adults
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Description/life cycle
The European corn borer (ECB) has a wide variety of host plants, but corn is the dominant host on the Prairies. The adult moth is light to dark brown with wavy bands on the wings. Larvae are often tan with darker plates with spines. The larvae reach about 30 mm (1.2 in.) in length when fully grown.

There is a single generation of ECB per year on the Canadian Prairies, with adults emerging from pupae toward the end of June. In Manitoba, adults remain present through to about mid-August, and there is no distinct peak of egg laying activity as the adults oviposit over a period of about 5 to 6 weeks.

Eggs are laid in masses on the underside of the leaf, often near the midrib. Larvae hatch in 5 to 7 days and feed outside in the leaf axils or whorl before tunnelling into the main stalk. Larvae then feed within the stalk and may move into the ears to feed as well.

Damage/symptoms
Feeding within the stalk may cause a reduction in the size of the ears. Direct feeding on the kernels within the ear renders the corn unsuited for the fresh market. Early damage is often seen as "pinholes" where the young larvae bore into the developing whorl. Later, damage is almost exclusively internal in the stalk or developing ear.

Control/management
Once the pest is inside the stalk, foliar application of insecticides is useless. Insecticide management is only possible in the period from oviposition (egg laying) to when larvae start to bore into the plant. Scouting for egg masses and young larvae can be difficult. Ensure that applications are timely and that they adhere to any pre-harvest intervals listed on the product labels.

Pheromone trap monitoring is possible but has been largely abandoned in the United States due to the failure of pheromones to detect adults on some occasions. Light trapping is possible but often attracts tremendous numbers of insects that require regular and frequent sorting.

Tillage and crop rotation are common cultural control practices. Fall ploughing or spring discing can eliminate a large proportion of overwintered larvae, but the potential of an outbreak from the remaining survivors is still present.

Disease management

Common rust (*Puccinia sorghi*)

Characteristic orange-coloured pustules of common rust
Photo: Robert Spencer

Description/disease cycle
Corn rust is a relatively common disease in many corn growing regions. However, because the spores arrive late in the growing season, it is generally of little concern in Western Canada. Poor growing conditions (e.g. years when accumulated heat units are quite low) could lead to potential problems with common rust.

In early spring, wind-blown spores generated on the alternate host (various *Oxalis* species, wood sorrel) are blown north from the southern US, where the rust overwinters. As new corn plants are infected, the inoculum levels increase. Arrival in the Prairie provinces may begin as early as June and as late as September.

Cool to moderate temperatures, high relative humidity and damp weather at the time of spore deposition are favourable for infection and disease development. Younger leaves are more susceptible to infection than older leaves.

Damage/symptoms
Initially, orange to yellow-brown blisters appear on the corn leaves. With the progression of the disease, these spots break open to release the rust-coloured spores.

Control/management
Planting earlier in the season can help ensure that the corn crop reaches a stage of growth where infection would have little effect. This approach is recommended if corn rust is a persistent problem. Grow resistant or tolerant cultivars if they are available and suitable for the region.

There are fungicide options that may be economical for sweet corn (where they would not be for field corn) if there is a rapid outbreak of common rust.

Crop rotation and burying debris are not useful techniques for managing this disease as spores arrive from other areas.

Corn ear moulds and kernel rots:

Generally, ear moulds and kernel rots have not been a problem in sweet corn production in Canada, although it may be that symptoms are not diagnosed as often or as easily as in field corn. Sweet corn hybrids tend to be harvested much sooner after silking than field corn, which may lead to insufficient time for symptoms to be expressed.

Diplodia ear rot (*Diplodia maydis*)

Description/disease cycle
As with the other ear rots, the fungal diplodia ear rot pathogen overwinters on crop residue. Therefore, the disease is often more prevalent in reduced tillage or when corn is grown back-to-back for multiple years.

The fungus can be introduced to the plant when spores produced in the residue are splashed onto the silks and grow into the ear. Infection can also occur via penetration of the base of the ear or when damage from birds and insects provides an access point for the fungus to gain entry.

Damage/symptoms
Diseased husks appear dry and bleached, while the rest of the plant is green. White to grey-brown mould grows from the base of the ear and

White-brown mycelium of diplodia ear rot
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

can expand to cover the entire ear. Extensive mycelium production gives the impression the husks are "glued" to the kernels. Diseased ears are light in colour and reduced in size. Later in the season, fungal fruiting structures develop, which give the husks and kernels a darker appearance.

If infection occurs later in the season, symptoms are not as easy to see. However, inspection of the ear will reveal the white mycelium growing between the kernels.

Control/management
Sweet corn cultivars vary in their tolerance to diplodia ear rot. Scout corn as soon as it begins to dent (at late ear development, just before physiological maturity). If ear rot is detected, fields should be harvested as soon as possible to prevent further mould growth and damaged corn.

Fusarium kernel rot, fusarium ear rot (*Fusarium moniliforme*, *Fusarium proliferatum*, *Fusarium subglutinans*)

Description/disease cycle
These fungi overwinter in soil and crop debris. Moist conditions promote the development of spores. Wind-borne spores germinate on the silks and grow through them, infecting the developing kernels. *Fusarium moniliforme* may also invade the ear through a systemic stalk infection. Warm, wet weather 2 to 3 weeks after silking is optimal for the disease to occur.

Damage/symptoms
Growth of the pathogen on the kernel and silks may vary in colour from white with a slight pink tinge to light purple. The growth is usually first observed at the tip of the ear or near any damaged areas. Light streaks radiating from a white centre to create a "starburst" symptom may be observed on infected kernels. Severe infections may have fungal growth between kernels, imparting a whitish, weathered appearance to the entire ear.

Control/management
Maintain good fertility and try to maintain adequate moisture throughout the season to minimize the potential for disease to occur. Also, employ practices to avoid wounding or damage, including managing insect damage, to reduce the chances of a fusarium ear rot outbreak.

Gibberella ear rot, red ear rot (*Fusarium graminearum*, *Gibberella zeae*)

Description/disease cycle
Of the ear rots that affect corn, gibberella ear rot is considered to be the most destructive and economically significant. The *Gibberella* fungus survives in soil and on cereal crop debris. *Fusarium graminearum* is a pathogen of cereal grains, and outbreaks of fusarium head blight in other cereals may be a source of spores during the growing season.

Infection may occur directly through the silks or through wounds (from insects, birds or other physical damage). Lodging of plants, often attributed to stalk rots, in which the ears come in direct contact with the soil, can also lead to ear rot development.

Wet weather is necessary for spore dispersal, and cool temperatures within a week after silking are especially favourable for gibberella ear rot. The individual kernels remain at risk of infection until they reach physiological maturity.

Damage/symptoms
A dark pink to red mould progresses from the tip of the ear to the base of the ear. A pink to white cottony growth may be observed. The husks may appear bleached and may adhere tightly to the ear.

Ear rots of corn (from top to bottom): Southern corn leaf blight (*Cochliobolus heterostrophus*), storage mould (*Aspergillus flavus*) and gibberella ear rot (*Fusarium graminearum*)
Photo: Department of Plant Pathology Archive, North Carolina State University, Bugwood.org

Control/management
Cultivars vary in their tolerance to gibberella ear rot. In general, tighter-husked hybrids tend to be less severely affected than those with loose husks.

Cultivation practices that reduce crop residues, such as fall tillage and rotating to crops other than cereals (due to fusarium head blight), may reduce the effect of gibberella ear rot in subsequent seasons.

Goss's wilt (*Clavibacter michiganensis* subsp. *nebraskensis*)

Description/disease cycle
Goss's wilt is a newer disease that has been found occasionally in corn in Manitoba, but not necessarily in sweet corn. However, it has been found in sweet corn (and other types) in other regions and poses a potentially serious threat to corn production.

This disease is caused by a bacterium. The pathogen overwinters on infected plant residue on the soil surface and can survive for close to a year on the residue. Infected residue is the primary source of inoculum, but the pathogen can also be seed-borne.

The bacterium can enter the plant through injured leaves (e.g. damaged by hail, sandblasting or heavy winds). It can be spread by wind-driven rain but is not transmitted by insects. Disease development is favoured by temperatures around 27°C (80°F). Hot, dry weather can slow development. All plant parts may be affected.

Damage/symptoms
Symptoms may occur as a systemic wilt and leaf blight. Leaf blight symptoms are most common.

Characteristic dark flecks in lesions caused by Goss's wilt
Photo: Courtesy L. E. Claflin; Reproduced, by permission, from White, D. G. 1999. Compendium of Corn Diseases, 3rd ed. American Phytopathological Society, St. Paul, Minn.

Discoloured vascular bundles caused by Goss's wilt
Photo: Courtesy L. E. Claflin; Reproduced, by permission, from White, D. G. 1999. Compendium of Corn Diseases, 3rd ed. American Phytopathological Society, St. Paul, Minn.

Water-soaked streaks may develop before the appearance of grey to pale yellow lesions with wavy margins that follow the leaf veins. A series of dark green to black water-soaked spots (referred to as "freckles") also occur and are considered diagnostic. An exudate on the leaves, which appears glistening or shiny when dry, is also characteristic of the leaf blight phase. Large portions of the leaves may become necrotic.

A wilt phase can also occur, where the vascular system becomes infected and the pathogen moves systemically throughout the plant. Xylem tissue (nutrient transport tissue) may become discoloured, and a slimy stalk rot can follow. Wilt results in premature death of the plant.

Control/management
No chemical controls are registered for this disease. Use resistant varieties (if available), adequate rotations and burial of crop residues to reduce inoculum levels.

Holcus spot (*Pseudomonas syringae* pv. *syringae*)

Description/disease cycle
Holcus spot is a bacterial disease that tends to show up in spring in areas of high moisture and high humidity as well as during periods of heavy rainfall. When infection occurs early in the development of the plant, it may cause concern, but typically, this leaf spot disease does very little damage.

The bacterium survives in crop residue in the soil. Frequent rains and temperatures of 25 to 30°C (77 to 86°F) favour disease outbreaks. Splashing water spreads the pathogen to the leaves where the bacteria enter wounds caused by hail, blowing soil or wind.

Damage/symptoms
Round to oval lesions appear first as green spots near the tips of the lower leaves. As the lesions dry out, they turn light brown with red to brown margins. Larger spots may have chlorotic areas surrounding them.

Holcus spot lesion on leaf
Photo: Robert Spencer

There have been reports that epiphytic (residing on the foliage surface but not feeding on the plant) populations of pv. *syringae* may increase the sensitivity of the plants to frost damage.

Control/management
Generally, this disease does not cause significant economic loss, and management strategies specific to holcus spot are rarely employed. In areas where this disease is a chronic problem, follow a two-year rotation that avoids corn, sorghum species, foxtail millet, Sudan grass and Johnson grass. Rotate with broadleaf crops. Maintain high levels of potassium. Overhead irrigation increases the chance of disease spread.

Northern corn leaf spot (*Bipolaris zeicola = Helminthosporium carbonum = Cochliobolus carbonum*)

Description/disease cycle
Northern corn leaf spot occurs mainly on inbred lines used in seed production, but has been found occasionally on sweet corn.

The fungus overwinters in infected leaves, husks and stalks of corn. Hardened overwintering structures known as chlamydospores are produced. The initial infection occurs on young plants that grow up through residues of the previous corn crop.

Infection and spread of the pathogen are favoured by temperatures of 18 to 26°C (64 to 79°F) and long periods of leaf wetness during the growing season. Moist conditions promote spore production, and large numbers of spores may be produced during the season. Dry conditions inhibit the spread of the fungus. Spores are dispersed by wind and may be carried for kilometres to other corn plants.

Damage/symptoms
Symptoms are first observed near silking or nearing full maturity. Northern leaf spot can be recognized by characteristic narrow, linear lesions ranging in width from about 3 to 6 mm (0.12 to 0.24 in.) and ranging in maximum length from 1 to 2 cm (0.4 to 0.8 in.). The lesions usually elongate linearly between the veins of the leaf as the leaf tissue expands.

Multiple lesions can give the appearance that lesions are elongated streaks on the leaves. The shape and colour of the lesions can vary by race of pathogen and corn genotype, but they are generally grey to tan. The leaf, leaf sheath, husks and ears may become infected.

Control/management
Planting resistant hybrids offers the best means of control.

To reduce the overwintering of the fungus in the field, maintain at least a one- to two-year crop rotation away from corn, or deeply bury infested corn residues by ploughing before planting corn again.

Fungicides are registered for the management of this disease. This disease and other similar or related diseases are often referred to as Helminthosporium leaf spots.

Smut diseases:

Common smut (*Ustilago maydis*)

Description/disease cycle
Smut spores can survive in soil or crop residue for years and germinate under favourable conditions. Spores can be transported into fields by air currents, draining surface water and farm equipment.

Young, actively growing and expanding plant tissues such as silks, cob tissues and developing kernels are the most susceptible. Splashing water can introduce spores onto young, developing corn tissues. The fungal spores germinate and can enter the plant directly through cell walls or via openings on the leaf surface such as wounds. After pollination, infection is less likely to occur.

After infection, rapid growth and distortion of host tissues follow, resulting in the formation of galls (swellings). Generally, development occurs at temperatures between 26 and 34°C (79 and 94°F).

Damage/symptoms
Common smut is one of the more easily recognized of the corn diseases. The chief symptoms are the formation of galls on leaves, tassels and seed heads.

Common smut galls on corn breaking open to reveal sooty black teliospores
Photo: Manitoba Agriculture, Food and Rural Development

Galls are most common on the developing ears. Initially, these galls have a smooth, greenish-grey-white surface, similar in texture to a mushroom. As the disease develops, the interiors of these galls darken and break open, releasing masses of powdery brown-black spores.

Leaf galls are usually about 1 cm (0.4 in.) in diameter and tend to appear as blisters. Leaf galls do not rupture. Galls on the rest of the plant tend to be larger (about 15 cm; 6 in.).

Control/management
Planting resistant cultivars is the best approach to manage common smut effectively. Maintaining crop rotations and using seed treatments can also help prevent the introduction and buildup of smut inoculum. Balanced fertility and practices that minimize plant damage are beneficial in reducing outbreaks of this disease.

Head smut (*Sphacelotheca reiliana*)

Description/disease cycle
Head smut is not generally common or commercially significant. Smut spores overwinter in the soil and can survive in the soil or on contaminated seed for over 10 years.

Germinating spores penetrate the surface tissues of developing seedlings and then develop systemically. Seedling infection is favoured by temperatures from 21 to 28°C (70 to 82°F). The plant's reproductive structures (ears, tassels) do not develop fully. Spores contaminate seed or fall to the soil.

Corn tassel infected with head smut; note masses of teliospores on surface of tassel
Photo: R.L. Croissant, Bugwood.org

Damage/symptoms
Black teliospores (thick-walled resting spore) occur over the surface of the developing ears and tassels. Sporulation does not generally happen on the leaf surfaces. Infected ears tend not to have any kernels. Tassels tend to be distorted and brush-like.

Head smut can be differentiated from common smut by the absence of galls and the presence of many clusters of spore-bearing structures on the tassels.

Control/management
This disease is best managed by rotating to non-host crops and attempting to reduce the amount of inoculum introduced to the field and soil. The use of seed treatments may reduce the effect of seed-borne inoculum. Many cultivars have resistance to head smut.

Weed management

Weeds in sweet corn may be controlled by cultural and/or chemical methods. The continuous use of the same control method can lead to the buildup of weeds tolerant or resistant to that method. Use as many available options as possible, including cultivation, crop rotation and chemical rotation.

Since corn is usually late planted, there is generally plenty of time to control the first flush of weeds by tillage or chemical sprays. Once corn becomes established, it is a good weed competitor, although wide row spacings will provide plenty of space for weeds to develop. Inter-row cultivation may be required when weeds escape herbicide treatments.

Consider herbicide residues when planning crop rotations, as some products used in corn (e.g. atrazine products) definitely cause issues in other crop types. These issues can carry-over, possibly for more than 1 year, thus limiting cropping options.

With some products, depending on the rate used and annual climatic conditions, replanting to corn (or planting some other grassy crop) may be necessary for 1 to 2 years following application.

Other requirements

Isolation

Certain sweet corn types need to be isolated from certain other corn types to prevent pollen contamination between the types and to ensure that each type maintains its own desirable qualities.

Se and *su* types of corn do not need to be isolated from each other. However, *sh2* types need to be isolated from field, *se*, *su* and synergistic corn types. *Shq* types must be isolated from *su* and *se* types.

Isolation of corn types can be achieved using a number of different techniques:

- Maintaining a spacing buffer of 76 to 213 m (250 to 700 ft.) between types will minimize pollen contamination.
- Staggering plantings according to date (both planting and maturity dates) can reduce contamination. Separation in time needs to be at least 14 days.
- Using two to five barrier or border rows between types will capture most of the pollen. These rows would not be harvested.

Harvesting

Sweet corn should be harvested when kernels are fully formed but still tender. As a general rule, most corn is ready about the time the silk turns brown or about 3 weeks after the silks first appear. Test for readiness by pressing the tips of the kernels with a fingernail. Kernel contents should spurt out when pressure is applied.

Post-harvest handling and storage

Handling fresh market corn after harvest

During warm weather, sweet corn quality deteriorates very quickly after harvest, and the sugars in the kernels are rapidly changed to starch. Sugar levels can start to go down within an hour of harvest, and noticeable deterioration can take place within hours. Supersweet varieties initially have a much higher sugar content and are, therefore, sweeter-tasting over a longer post-harvest period.

The changeover from sugar to starch is almost completely stopped if the temperature of the corn is brought down to 2 to 5°C (36 to 41°F) within an hour of harvest and then maintained at this low level or cooler during shipping and marketing.

The removal of field heat is best done by flushing graded and bagged corn with iced water (0°C; 32°F), a process called hydro-cooling. The key to hydro-cooling is using enough ice to maintain low water temperatures and flushing the corn for a long enough time to bring the temperatures down.

Storage and handling

Sweet corn should be marketed as quickly as possible. It can be held for shipment for 1 or 2 days at 0°C (32°F) and a relative humidity greater than 95 per cent.

Cucurbits (cucumbers, summer squash, winter squash, pumpkins, melons)

Different shapes of summer squash

Varieties/cultivars

Cucumbers

Many cucumber varieties and types have been bred for specific intended uses, ranging from large types for fresh use to smaller types for pickling.

Squash

Summer squash are available in various shapes and colours. This group includes zucchini, scallop squashes and other types. Summer squash ripen earlier than winter squash and do not store as well.

Types of winter squash

Winter squash are available in a range of sizes, shapes and colours. This group includes acorn, buttercup, butternut, Hubbard, spaghetti squash, etc. They have a range of uses and can be stored for longer periods than summer squash.

Pumpkins

Pie pumpkins typically have small fruit with thick walls and a small, seedy interior. The fruit have a high sugar content and excellent storage potential.

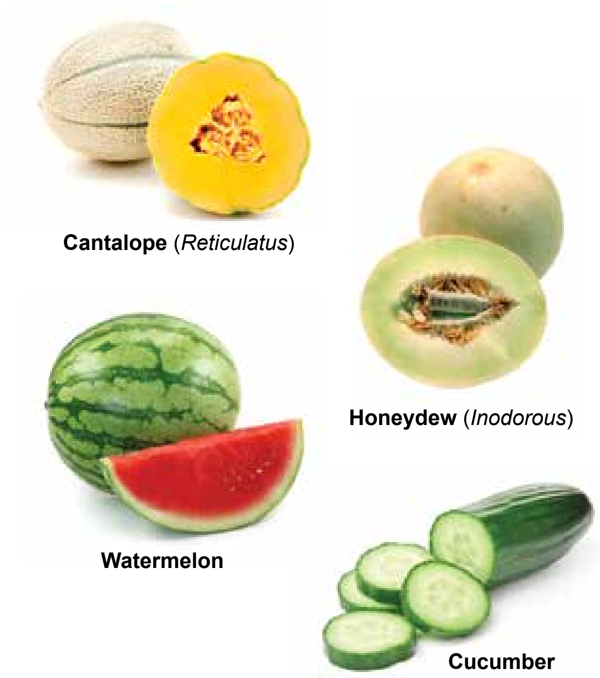
Carving pumpkins have larger fruit with thinner walls and a large internal cavity. The flesh tends to be watery and fibrous with lower sugar content than pie types.

Melons

The *Reticulatus* group of melons has a characteristic netted skin. When ripe, these melons are aromatic and the fruit slips off the vine. This group includes the galia and charentais melons as well as cantaloupe and muskmelon.

The *Inodorous* group has a smooth skin. When mature, these melons lack a musky aroma and do not slip from the vine. Casaba, crenshaw and honeydew melons are included in this group.

Cantaloupe has early maturing fruit with firm, thick, yellow-orange flesh. Mature fruit have a characteristic musky odour, and they slip from the vine. Cantaloupes are further divided into



Cucumber and melons

eastern and western types. The eastern type fruit are round, sutured with a variable level of netting and a large seed cavity. The western type fruit are more oval and tend to be smooth (no sutures) with a coarsely netted rind.

Casaba has oval fruit with a pointy end and wrinkled yellow skin. The flesh is almost white and extremely sweet.

Charentais (also called: French charentais) has small fruit with smooth grey or grey-blue rinds and aromatic orange flesh.

Crenshaw (also called: cranshaw) has large, oblong fruit with wrinkled green rinds that ripen to yellow. The flesh is pale orange.

Galia has small pale fruit with netted rinds. The flesh is green to yellow. These melons are suited to greenhouse production.

Honeydew fruit has smooth, white to greenish-white rinds, light green or orange, sweet flesh and a mild aromatic flavour.

Watermelon has fruit with smooth, green rinds, reddish pink or yellow watery flesh and a mild flavour. It is difficult to grow successfully in most parts of the Prairies because it requires a long season and lots of heat units.

Climate and soil requirements

All cucurbits are warm-season, frost-tender crops. Seeding and transplanting should be done into warmer soils after all risk of frost has passed. Cucurbit crops grow best at temperatures between 18 and 24°C (65 and 75°F), tolerating up to 32°C (90°F).

Cucurbits can be grown on a range of soil types, provided the soil is well drained. Heavier soils may produce higher yields and prolonged fruiting in crops like cucumbers. Irrigation may be required on lighter soils.

Planting

Because cucurbits are warm-season crops, soil temperatures must be 16°C (60°F) or higher before germination occurs. Cucurbits will not grow at temperatures less than 10°C (50°F). They have no frost tolerance and must be planted after all danger of frost has passed.

Pickling cucumbers will mature from seed in most areas. In some of the more southern regions of the Prairies, slicing cucumbers, squash, pumpkins and melons may also mature when direct seeded into the field.

However, all cucurbit production can be less risky, earlier and higher yielding, especially in more northern areas, if the crops are grown from transplants. Other techniques that enhance and extend the growing season, such as plastic mulch and tunnels, will also improve yields, enhance earliness and reduce production risks. See the Growing Season Extension section in the Field Production chapter for more information on the use of these tools.

Cucurbit transplants should be started about 3 to 4 weeks before planting into the field. Older transplants are prone to transplanting shock.

When direct seeding, sow smaller-seeded types (cucumbers and melons) at a depth of 1.3 to 2.5 cm (1/2 to 1 in.), and sow larger-seeded types (pumpkins and squash) 2.5 to 5 cm (1 to 2 in.) deep.

Maximizing plant density increases yields, while decreasing weeding issues. However, high plant densities may increase the risk of disease due to excessively dense canopies and may cause issues during harvesting.

Table 33 lists the typical weights of seed for growing transplants or seeds required for planting various cucurbits. Seed sizes vary greatly, and seed counts per kilogram (per pound) will help in determining amounts required.

Table 34 identifies typical between-row and within-row spacings for cucurbits.

Table 33. Approximate cucurbit seed requirements

Cucurbit type	Transplants		Direct seeded	
	(kg/ha)	(lb./ac.)	(kg/ha)	(lb./ac.)
Cucumbers (pickling)	1.1 - 2.7	1 - 2	4.5 - 5.7	4 - 5
Cucumbers (slicing)	1.1 - 2.7	1 - 2	3.4 - 4.5	3 - 4
Pumpkins, squash (large seed)	2.7	2	3.4 - 4.5	3 - 4
Pumpkins, squash (small seed)	1.1 - 2.7	1 - 2	1.1 - 3.4	1 - 3
Muskmelons	1.1 - 2.7	1 - 2	-	-
Watermelons	1.1	1	-	-

Table 34. Approximate final spacings for cucurbit crops*

Cucurbit type	Between rows		Within rows	
	(cm)	(ft.)	(cm)	(in.)
Cucumbers (pickling)	120 - 180	4 - 6	7.5 - 15	3 - 6
Cucumbers (slicing)	120 - 180	4 - 6	30	12
Muskmelons	180	6	60	24
Pumpkins (bush)	90 - 120	3 - 4	90	36
Pumpkins (vining), squash (vining)	180 - 240	6 - 8	60 - 90	24 - 36
Squash (summer - bush types)	120 - 210	4 - 5	45 - 60	18 - 24
Watermelons	180	6	60	24

* Between-row and within-row spacing can be adjusted based on estimated plant size, field layout and equipment types.

Fertilizer

ALWAYS base fertilizer application rates on the results of annual soil tests. Before planting, broadcast and incorporate up to the following:

- 63 kg N/ha (57 lb. N/ac.)
- 121 to 143 kg P/ha (110 to 130 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)

As a general rule, an application of 28 kg S/ha (25 lb. S/ac.) is recommended. Reduce phosphorus and potassium rates to one-fifth and one-half, respectively, if side-banding.

Side-dress with an additional 29 to 33 kg N/ha (26 to 30 lb. N/ac.) when plants start to run. This later application can be applied through the irrigation system.

Irrigation

Cucurbits require uniform moisture throughout the growing season. Apply 25 mm (1 in.) of water (including precipitation) after seeding or transplanting. Critical moisture periods for cucurbits are during flowering and fruit set, development and sizing. In general, cucurbits use approximately 200 to 250 mm (8 to 10 in.) of water in a growing season (including precipitation).

Uniform watering reduces issues with fruit splitting. It is important to watch for diseases related to foliar wetness. Apply water using drip irrigation and/or by irrigating early in the day. Fruit in contact with water-saturated soil is prone to rotting.

Insect pest management

Cucumber beetles (striped – *Acalymma vittatum*; spotted – *Diabrotica undecimpunctata howardi*)

Feeding striped cucumber beetle larvae
Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Adult striped cucumber beetle
Photo: Manitoba Agriculture, Food and Rural Development

Striped cucumber beetle damage on cucurbit seedling
Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Spotted cucumber beetle larvae emerging from stem
Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Adult spotted cucumber beetle
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
The spotted cucumber beetle is yellow with 12 dark spots on the elytra (case covering the insect's body). The striped cucumber beetle is yellow with longitudinal black stripes. Both beetles are 5 to 7 mm (0.2 to 0.28 in.) in length. Larvae of both species are slender, legless and 10 mm (0.4 in.) long with white bodies and reddish heads.

Both species overwinter as adults in protected areas around fields. Adults move into fields in early June and begin feeding on leaves and stems. Eggs are laid in the ground near the host.

The larvae hatch within 10 days and feed on the roots for about a month, then pupate in the soil. Adults emerge 2 weeks after pupation and may feed on the rind of fruits until the first hard frost.

Damage/symptoms
Early season adult feeding damage gives a shot hole appearance to the leaves and cotyledons, but this damage is seldom of economic significance. Feeding close to the ground by adults can result in broken stems, leading to plant death. Larvae tunnel into the base of the plant and roots, which may cause wilting.

The most damaging aspect of these pests is that they transmit bacterial wilt and cucumber mosaic virus (CMV is also transmitted by aphids), both of which cause far greater economic damage than direct feeding. For information, see Bacterial Wilt and Cucumber Mosaic Virus in the Disease Management section.

Control/management
It is impossible to tell if natural enemies play a role in controlling cucumber beetles, so chemical control of initial adult populations is the best management strategy. The adult beetles are readily controlled by the application of contact insecticides before full flowering. Scouting is accomplished visually.

Two-spotted spider mite (*Tetranychus urticae*)

Two-spotted spider mites and webbing
Photo: Manitoba Agriculture, Food and Rural Development

Description/life cycle
Mites are tiny arthropods that go through four life stages (egg, larva, nymph and adult) and can do so very quickly in hot, dry conditions. Multiple generations are possible in a growing season.

Cucumber fruit damaged by two-spotted spider mites
Photo: Manitoba Agriculture, Food and Rural Development

Mites are typically only 0.4 to 0.5 mm (0.02 in.) long when mature and are most easily detected by the webbing on the underside of the leaf surface.

Damage/symptoms
While not typically a problem in most years, two-spotted spider mites can be a late season problem in cucumbers during hot, dry years. The larval and adult mites feed on the underside of the leaf surface, sucking out the sap. They can cause severe defoliation in hot, dry conditions.

They do not attack the fruit directly, but foliage damage results in small, low quality fruit. Infestations typically occur at field margins first.

Control/management
Natural enemies often keep mite populations in check. However, under suitable weather conditions, populations can build up extremely rapidly (a generation in 5 to 7 days under optimal conditions), overwhelming the natural enemies with sheer numbers.

Insecticides applied to control cucumber beetles may kill natural enemies that otherwise keep mites in check. If you must treat for beetles, watch for subsequent mite problems. Spot spraying may be effective as mites are not overly mobile.

Disease management

Angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*)

Description/disease cycle
Angular leaf spot disease is widespread and can occur anywhere on the Prairies.

The pathogen can survive in soil and crop residues for about 2 years. Splashing water from rain or irrigation sprinklers can spread the disease. When diseased seed is planted, the cotyledons can become infected. Spread of the bacterium from plant to plant can also occur. Insects and contact by personnel or equipment can also spread the bacterium throughout a field.

Humid conditions with temperatures between 24 and 28°C (75 and 82°F) are optimal for disease development.

Damage/symptoms
Grey, small, round or irregularly shaped lesions appear initially. These lesions expand until they reach larger secondary veins, which give the lesions an angular appearance. Lesions may be surrounded by chlorotic tissue.

Leaf lesions of angular leaf spot
Photo: R.J. Howard, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

As the lesions age, they take on a tan colour, dry out and may fall out of the leaf, giving the leaf a tattered appearance. Under humid conditions, bacterial ooze may issue from the lesions. Upon drying, a white residue may remain on the leaf surface.

Fruit infections appear as water-soaked, round lesions that later turn brown. An internal rot may follow, and fruit will become unmarketable through the activity of secondary decay organisms.

Control/management

Use pathogen-free seed. Seed treatments can be of some benefit. Bury crop residue immediately after harvest. Use a minimum three-year rotation with no cucurbits in the field, and be sure to destroy any volunteers.

Do not use overhead irrigation. Use fields or parts of the field that will allow for quick drying of foliage. Do not conduct field operations while the crop is wet.

Bacterial wilt (*Erwinia tracheiphila*)

Description/disease cycle

Bacterial wilt is vectored by spotted and striped cucumber beetles (see Cucumber Beetles in the previous Insect Management section). Muskmelons and cucumbers can be severely affected by this disease. Other cucurbits may be infected, but the disease is typically much less severe.

The initial source of the bacterium is uncertain. Seed-borne transmission has not been demonstrated. Persistence of the pathogen in the beetle's gut was considered in past studies, but recent studies suggest this situation is not the case.

The bacterium can survive in dried tissue for a short period and can only survive in soil for 2 to 3 months. It is possible that insect vectors acquire the pathogen from infected weeds.

The beetle's mouth parts acquire the bacteria when feeding on infected plant tissue. The beetle then transmits the bacteria to a new host by feeding on that host. The bacteria spread through the water-conducting cells of the plant (xylem). Through increased bacterial growth and the production of various compounds, the vascular tissue may become blocked. Damage tends to be the most severe on young, succulent plants.

Damage/symptoms

Wilting leaves are the first symptom of this disease, gradually increasing in severity. Diseased foliage becomes darker before turning yellow and then brown. Advanced infections can lead to the collapse of entire plants. Cutting a stem and slowly pulling it apart may reveal strands of bacteria exuding from the tissues. Fruit infections appear as small, water-soaked lesions on the surface.

Bacterial wilt, caused by *Erwinia tracheiphila* on melon

Photo: Courtesy R. X. Latin; Reproduced, by permission, from Zitter, T. A., Hopkins, D. L. and Thomas, C. E. 1996. Compendium of Cucurbit Diseases. American Phytopathological Society, St. Paul, Minn.

Control/management

Use resistant cultivars, if available, and manage the insect vectors to reduce the spread of the bacteria.

Powdery mildew (*Podospheara xanthii* (formerly *Sphaerotheca fuliginea*) and *Golovinomyces cichoracearum* (formerly *Erysiphe cichoracearum*))

Description/disease cycle

Powdery mildew damage can be a significant production problem in greenhouse-grown cucurbits. In the field, the disease is of relatively little concern, but occasional outbreaks do occur. These outbreaks generally occur late in the season, shortly before harvest, and result in little damage.

The fungi that cause powdery mildew can only grow on living hosts (that is, they are obligate parasites). It is uncertain whether the pathogens overwinter in fruiting structures on the Prairies, but it appears unlikely. Greenhouse-grown cucurbits may be a source of spores, which can be blown for long distances.

Under favourable conditions, powdery mildew can develop rapidly. Symptoms may occur as little as 3 days after infection, with large numbers of spores produced. High relative humidity is favourable for infection, but infection may occur even at humidity levels below 50 per cent. Dense plant growth and low light can favour disease development; the canopies of many cucurbit crops provide these conditions.

Optimal temperatures for disease development are between 20 and 27°C (68 and 81°F); however, infection can occur between 10 and 32°C (50 and 90°F).

Damage/symptoms
Initially, white powdery or dusty growth occurs on upper and lower leaf surfaces, petioles and stems. Typically, the older leaves become diseased first. Leaf tissues may become chlorotic and can wither and die. Fruit infection is uncommon.

Control/management
Resistant cultivars and registered fungicide applications are the best tools available to manage powdery mildew. As many cucurbits have extensive, dense canopies, getting the product to all the surfaces of the plant can be difficult.

Cucumber mosaic virus

Description/disease cycle
Over 1,200 plant species worldwide are hosts to the cucumber mosaic virus pathogen, including many vegetable crops.

Cucumber mosaic virus (CMV) survives each year by moving between alternate hosts through insect vectors, including many species of aphids and the striped and spotted cucumber beetles. Vectors become inoculated almost immediately but do not remain infective for very long. The virus can also be spread in plant sap during pruning or harvest operations. It is rarely transmitted by seed.

The virus moves systemically within the plant. Symptoms appear in 1 to 2 weeks, depending on plant age. Symptom development is faster at hot temperatures (over 25°C; 77°F) and more severe in short days or low light conditions.

Masses of powdery mildew spores
Photo: Manitoba Agriculture, Food and Rural Development

Damage/symptoms
Plants may be infected at any stage, but cucumber is most often infected during rapid growth at the six- to eight-leaf stage. Cotyledons wilt and turn yellow, and plants are stunted. New growth will be distorted and may be mottled. Older plants may have smaller-sized new leaves with some mottling. Fruit set is minimal and discoloured. Plants may wilt at varying rates.

Control/management
Management and removal of alternate hosts within 100 m (328 ft.) of the cucurbit field can help reduce inoculum sources. Rapid control of insect vectors can slow spread of the virus. Avoid or reduce the handling of infected plants.

Leaves damaged by cucumber mosaic virus
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Weed management

As cucurbits produce a vigorous, sprawling canopy, they are fairly good at competing with weeds, especially once they begin to vine out in mid-season. Early season weed control is important. Control perennial weeds before planting.

Only a limited number of chemical controls are available for weed management in cucurbits, particularly for broadleaf weed control. Consider the residual effect of applied herbicides on the current crop and subsequent crops in the rotation.

Application of some herbicides during very wet, cold weather can cause stunting of the crop. Not all herbicides registered for use on one cucurbit are registered for all other cucurbits. Be sure to read and follow all product label directions.

Other requirements

Pollination

All cucurbits depend on insects to transfer pollen from the male to female blossoms. In small plantings, there may be enough native insects to perform this critical service. In large plantings, provide one colony of honeybees for every 0.5 to 1.5 ha (1.5 to 3.5 ac.) to ensure adequate pollination. Insufficient pollination will result in poor yields and lots of small, distorted fruit.

To grow seedless watermelon, you MUST also plant a standard diploid pollinator variety or the seedless variety will not set any fruit. It is commonly recommended to plant one pollinator plant for every two seedless watermelon plants, interspersed within each row.

Harvesting

Cucurbits vary in the time when they should be harvested. Some crops, such as cucumbers or summer squash, should be picked when the fruit are small and tender, with the optimum size and degree of maturity depending on the type.

Others, such as pumpkins and winter squash, must be mature at harvest and may require further post-harvest ripening.

Melons, such as cantaloupe and muskmelon, should be harvested at full-slip (when stem separates easily from fruit – note: some types do not slip) and/or when soluble solid (sugar) contents are highest. While harvesting at full-slip will result in fruit that are high quality, the fruit will also have a very short post-harvest lifespan and reduced shipping potential.

Post-harvest handling and storage

All cucurbits should be graded before attempting to store them. Remove damaged, immature or frozen fruit. Only quality product should be stored.

Cucumbers and summer squash should be stored at temperatures between 7 to 9°C (45 to 48°F) and more than 95 per cent relative humidity. A storage life of 10 to 14 days can be expected. Cucumbers and summer squash are sensitive to chilling injury at temperatures below 7°C (45°F).

Muskmelons store best at 0 to 7°C (32 to 45°F) and 90 per cent relative humidity. Muskmelons normally have a storage life of about 2 weeks at 0°C (32°F). However, some varieties suffer from low temperature breakdown at 0 to 7°C (32 to 45°F). Only mature melons should be stored.

Pumpkins and winter squash store best at temperatures between 7 to 15°C (45 to 59°F) and 50 to 75 per cent relative humidity. Pumpkins and some types of winter squash should be cured for 10 to 20 days at 24 to 30°C (75 to 86°F) immediately after harvest to aid the healing of minor injuries. Mature but green pumpkins will colour up during this curing stage. Curing also reduces water content and can improve eating quality of some types of squash (butternut, Hubbard, etc.). Acorn squash should not be cured.

After curing, temperatures should be reduced to the 7 to 15°C (45 to 59°F) range. Lower relative humidities may reduce or slow the development of storage rots but will increase water loss and shrinkage. Water losses should be kept under 15 per cent.

The storage life of pumpkins and squash depends largely on their type and variety. In general, pumpkins can be stored for 8 to 12 weeks, provided quality was good entering storage. Acorn squash can be stored for 4 to 7 weeks, butternut squash for 8 to 12 weeks, buttercup squash for up to 10 weeks, turban squash for 12 weeks and Hubbard squash for up to 6 months.

Peas (succulent)

Varieties/cultivars

Snow peas (*Pisum sativum* var. *sacchartum*) have a non-fibrous flattened pod that is eaten while still unripe.

Sugarsnap peas (*Pisum sativum* var. *macrocarpon*) were developed by crossing snow peas with a mutant shell pea. The rounded non-fibrous pod is eaten while still unripe.

With **fresh or garden peas** (*Pisum sativum* var. *sativum*), the immature seed is removed from the pod and eaten when tender and sweet.

Climate and soil requirements

Peas are generally considered a cool-season crop. They produce well in most areas of the Prairies. Peas generally grow best in the temperature range of 16 to 18°C (60 to 65°F), tolerating up to 24°C (75°F).

Peas may be grown on a wide range of well drained soil types.

Planting

Peas may be planted when soil temperatures reach 4°C (39°F). Plantings may be staggered to stretch out harvest dates; however, planting should begin as early as possible.

Peas should be planted into moist soil to a depth of about 2.5 to 5 cm (1 to 2 in.). Seeding rates vary considerably depending on variety, seed size, per cent germination and the availability of irrigation. Seeding rates can range from 99 to 297 kg/ha (90 to 270 lb./ac.).

Row spacing and layout depend on equipment and harvesting practices (e.g. u-pick versus pre-picked versus machine harvested). Peas may be planted in rows with 60 cm (24 in.) between rows. Alternatively, they may be planted in beds of rows 15 to 25 cm (6 to 10 in.) apart, leaving a walkway between beds every 120 to 180 cm (4 to 6 ft.). In all cases, seeds are planted about 2 to 5 cm (1 to 2 in.) apart within the row.

Fertilizer

In general, peas do not require a great deal of fertilizer, particularly nitrogen. Peas are legumes, so they have the ability to fix nitrogen with the help of certain bacteria.

ALWAYS base fertilizer applications on the results of annual soil tests. A small amount of nitrogen may be applied before planting. Potassium is only applied when soils are extremely deficient. Apply phosphorus before seeding based on soil tests.

Irrigation

Peas can be grown without irrigation but may benefit from it depending on the year, the region and the soil type. Peas use approximately 375 mm (15 in.) of moisture per season (including precipitation) and can use up 5.5 to 6 mm (0.2 to 0.25 in.) of water per day during peak use. Critical moisture periods are during flowering, pod set and pod fill.

Insect pest management

Pea aphid (*Acyrthosiphon pisum*)

Description/life cycle

The pea aphid is a small, light green aphid up to 5 mm (0.2 in.) in length. As with all aphids, it may be winged or wingless. It is the only aphid species that commonly occurs on field pea in the Prairies.

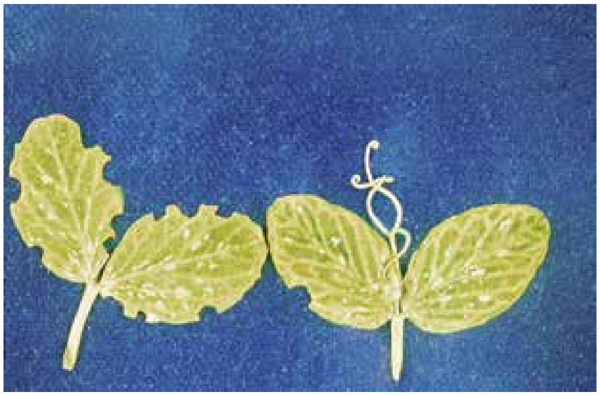
Damage/symptoms

Aphids use their piercing and sucking mouth parts to suck plant sap. Feeding is usually done on young foliage near the growing tips. Heavy aphid infestations can cause damage during flowering and seed formation, typically reducing seed sizes and lowering yields.

Control/management

The economic threshold for pea aphid is two to three aphids per stem tip at the flowering stage. Chemical control should only be applied when thresholds are exceeded because biological control measures often provide ample control.

Pea leaf weevil (*Sitona lineatus*)



U-shaped leaf edge notching, caused by adult pea leaf weevils

Photo: Courtesy F. Muehlbauer; Reproduced from Kraft, J. M. and Pfleger, F. L. 2001. Compendium of Pea Diseases and Pests, 2nd ed. American Phytopathological Society, St. Paul, Minn.

Description/life cycle

The pea leaf weevil is not typically found in the Prairies. A population of pea leaf weevil has developed in southern Alberta, although it is more typically an economic issue on field peas rather than fresh peas. Adults overwinter in crop residue and emerge to feed on seedlings.

Damage/symptoms

Adults chew notches in leaf margins, and the larvae feed on root nodules. Larval feeding can reduce plant vigour and can reduce nodulation in field peas.

Control/management

Crop rotation is usually sufficient to manage this pest. Chemical control options are limited and are for controlling the adults. Fertilizing with nitrogen can often compensate for larval feeding on root nodules.

Disease management

Ascochyta leaf and pod spot, Mycosphaerella blight (*Ascochyta pisi*; *Mycosphaerella pinodes*)

Description/disease cycle
The above-named diseases are caused by a complex of closely related fungi that are present worldwide wherever peas are grown. Depending on the pathogen, hosts may include various types of peas and beans. These pathogens affect pods as well as seedlings, older leaves and stems.

Although all these pathogens are seed-borne, some types can survive on crop debris. Ascospores are formed and ejected into the air to be spread by the wind over large areas. Dry conditions are required for ascospore dispersal, whereas high humidity is required for spore germination.

As the pathogen continues to develop and spread within the crop, spores are produced by pycnidia (small, black fruiting bodies) in lesions and dispersed to surrounding foliage and pods by rain or water splash. Spores germinate and penetrate cell walls directly.

Damage/symptoms
Symptoms can vary depending on the pathogen species. *Ascochyta pisi* causes slightly sunken, dark-edged, tan to brown lesions on leaves, pods and stems. Lesion shape varies from circular leaf lesions to somewhat more elongate stem lesions. Pycnidia are often found in the middle of the lesions.

Mycosphaerella pinodes causes dark flecking on leaves, pods and stems. These symptoms then increase and become larger to form rings of alternating brown and tan. Stem lesions tend to be blue-black or purplish. As the lesions become longer and wider, they girdle the stem. Infected blossoms may fall off.

Ascochyta pod lesions
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Foliar and stem dieback from ascochyta leaf and pod spot
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Control/management
Maintain crop rotations of 4 to 5 years between pea crops. Use clean seed or seed produced in drier areas to avoid introducing the fungi into fields. Use less susceptible cultivars, if available.

Avoid prolonged periods of irrigation to allow the foliage to dry out. Infected vines should be removed or incorporated into the soil shortly after harvest.

If applied appropriately, registered fungicides may be useful in reducing infection and disease spread during wet periods. Seed treatments may also be useful.

Downy mildew (*Peronospora viciae*)

Description/disease cycle

Soil-borne resting spores (oospores) of the downy mildew fungus can survive in the soil for up to 15 years. Germinating pea seeds can stimulate the oospores to initiate infection of the young pea seedlings.

As the infection develops, velvet-like threads (mycelium) start to grow on the bottom of the leaves. Periods of high relative humidity cause sporangia (a structure containing spores) to be released, resulting in secondary infections. Once in contact with new leaf tissue, small lesions appear, and the mycelium grow across the surface. Within the pods, oospores are produced.

Upon harvesting the crop, the spores remain in crop debris and the soil, representing a disease risk for several years.

Disease development is favoured by high relative humidity (over 90 per cent) and temperatures between 1 and 20°C (34 and 68°F), although spore germination is optimum at 4 to 8°C (39 to 46°F). Sporangial survival increases as temperature decreases.

Damage/symptoms

At the field level, downy mildew symptoms cause groups of young plants to appear pale and stunted. Examination of the underside of the leaves reveals a purple fuzzy growth of mycelium. On the upper leaf surface are blotches that correspond to the areas of fungal growth on the underside of the leaf.

Downy mildew mycelium inside pea pods
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Leaf lesions caused by downy mildew
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

As the plants develop, systemic infection from air-borne spores begins at the growing point, which can cause shortened internodes (part of plant stem from which leaves emerge). Profuse fungal growth in the pods will lead to uneven pod fill and poor seed development. Secondary decay organisms may exploit the damage caused.

Control/management

Some pea cultivars tolerate this disease. In areas where this disease is a recurring problem, consider a seed treatment. There can be severe losses when crops are sown early in the season because this disease can thrive at lower temperatures, while crop growth is slowed. Maintain at least a three-year rotation between host crops, and bury infected crop residue.

Powdery mildew (*Erysiphe pisi*)

Description/disease cycle

Powdery mildew has been somewhat less of a problem in recent years as resistant pea cultivars are increasingly available. However, this disease can be found almost anywhere. Powdery mildew can be a potential problem in areas when nights are cool and promote dew formation.

The disease cycle can be completed in as little as just 1 week. Conidia are produced on infected crop debris or infected plants. These spores can infect plants without free water on foliage surfaces and can infect even at low relative humidity. The disease tends to worsen as the season progresses. Late summer in the Prairies often provides environmental conditions that favour the disease.

Severe cases of powdery mildew reduce seed quality, discolour seeds and harm flavour.

The forms of *Erysiphe pisi* on pea only infect pea. Other forms of *Erysiphe pisi* cause powdery mildews that affect alfalfa, vetch, chickpea and lentil.

Damage/symptoms
Initially, discoloured areas appear on the upper surfaces of the oldest leaves. Then, blotches of powdery spores appear on the upper surface of the lowest leaves. The entire leaf may turn white and dusty as the fungus continues to grow and the blotches coalesce. Lesions spread rapidly up the plant.

Pea leaf infected with powdery mildew
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

As the disease develops, the pods may become infected. With the production of fungal fruiting bodies, the white areas turn grey; this symptom is most apparent on the pods. The plants may have a fish-like odour.

In severe infestations, the foliage will senesce and dry out. Later in the season, any affected plants that have not been severely diseased may appear purple to yellow due to desiccated foliage.

Control/management
Use cultivars that are more resistant or tolerant of powdery mildew. Consider seeding early to avoid infection early in the season, as early infection has the greatest effect on the plant.

Destroy or plough under diseased crop debris. Rotate crops to allow 4 years between pea crops.

Irrigation with overhead sprinklers can lower disease severity, as the pathogen does not like wet conditions. However, the disease may develop if the canopy does not dry out or if humidity levels remain high.

Weed management

In general, peas are decent competitors as they do well in cool soils and rapidly produce a thick, sprawling canopy that smoothers weed competitors.

Control perennial weeds before planting. A good number of registered chemical control options are available, including pre-plant and pre- and post-emergent. Follow label rates and application instructions. Consider the effect of herbicide use on other crops in the rotation.

Harvesting

Green peas (garden peas) should be harvested before physiological maturity, when seeds have filled out but are still tender and sweet. Over-mature peas are starchy and tough, with poor flavour. Snow peas should have fully formed pods, with little or no seed development.
All quality peas are green, turgid and free of deformities.

Multiple harvests are typical for fresh market peas, although some cultivars are well suited to a single, once-over mechanical harvest.

Post-harvest handling and storage

Peas should be cooled as rapidly as possible to remove field heat. Fresh peas store best at 0°C (32°F) and relative humidity greater than 95 per cent. If peas are to be stored at all, they should be stored in the pod. A storage life of 4 to 7 days can be expected.

Tomatoes, peppers, eggplants

Varieties/cultivars

Tomatoes
Tomato varieties are divided into several categories, based mostly on shape and size.

Beefsteak tomatoes are large and used fresh on sandwiches and for similar applications. Their kidney-bean shape, thin skin and short shelf life make commercial use of beefsteak tomatoes impractical.

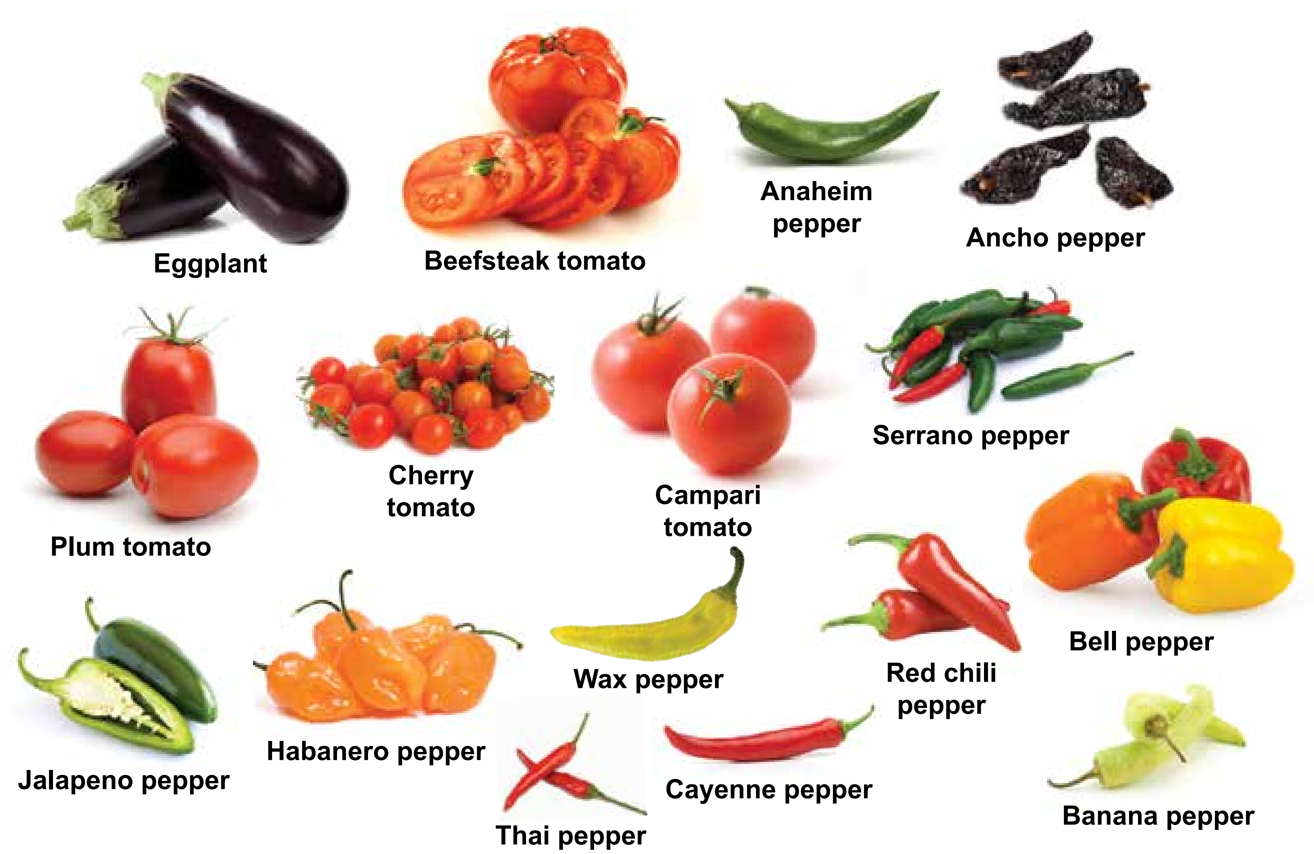
Plum tomatoes (also called: paste, roma or pear tomatoes) are small, oval to pear-shaped with thick skin and a high solid content. These tomatoes were bred for use in sauce, but since they store and handle well, they are also popular as salad items.

Cherry tomatoes are small, round, sweet yet tart. They are generally served whole in salads. Grape tomatoes are a recent introduction in this category.

Campari tomatoes are sweet and juicy with low acidity. They are bigger than cherry tomatoes, but smaller than plum tomatoes.

Peppers
Peppers are divided into categories based on the shape and pungency of the fruit. Pungency is rated in Scoville units, with standard green bell peppers having a Scoville rating of 0 while the relatively hot habanero type peppers have a Scoville rating of about 500,000. The commercially produced pepper with the highest ranking on the Scoville scale is just under 1,500,000.

The *Anaheim chile* (also called: California green, long green, chile verde, New Mexican) is a large, mild fruit with a thick skin. It is 12.5 cm (5 to 8 in.) long and 3.75 to 5 cm (1.5 to 2 in.) wide, and tapers to a point. The bright, shiny green fruit matures to red or yellow. It ranges from mild and sweet to moderately hot. When



Different types of tomatoes, peppers and eggplant

green, the fruit are used fresh, canned or frozen. The mature fruit are usually dried and ground into chili powder if hot or paprika if sweet.
Scoville rating: 2,500

Ancho peppers (also called: poblano when fresh and ancho when dried) have heart-shaped, pointed fruit with an indented stem attachment. Immature fruit are dark green, and mature fruit are red or brown. The fruit are 7.5 to 10 cm (3 to 4 in.) long and about 5 cm (2 in.) wide. They are not very hot but have exceptional flavour.
Scoville rating: 2,000

Banana peppers (also called: pimento) have banana-shaped fruit that change from pale to deep yellow, red or orange as they mature. The fruit have a sweet, mild flavour but are easily mistaken for hotter yellow wax peppers. They tend to be early maturing.
Scoville rating: 500

Cayenne peppers have an elongated, wrinkled, irregularly shaped fruit. The fruit is 12.5 to 25 cm (5 to 10 in.) long and 1.8 to 2.5 cm (0.75 to 1 in.) in diameter. It changes to red when mature. It is highly pungent, even when small. The pepper can be used fresh or dried.
Scoville rating: 60,000

Habanero peppers (also called: Scotch bonnet, Bahamian, chinense) have small, irregular, oval, thin-walled fruit that mature to orange or red. This pepper is slow growing. The fruit are extremely hot and can be used fresh or dried.
Scoville rating: 325,000 to 570,000

Jalapeño peppers have a thick-walled, conical-shaped, dark green fruit that turns red at maturity. The fruit vary from mild to pungent. They can be used canned, pickled, in salsas or fresh. When dried by smoking, they are called chipotle.
Scoville rating: 5,000

Red chili has small, tapered, thin-walled fruit that turn from green to red when mature. They are 1.25 cm (0.5 in.) wide and 6.25 cm (2.5 in.) long. The fruit are used dried for processing and for sauce.
Scoville rating: 100,000

Serrano pepper has fruit 3.75 cm (1.5 in.) wide and 5 to 7.5 cm (2 to 3 in.) long with medium thick, waxy walls. Their shape is similar to jalapeño peppers, but the fruit tends to be larger. They change from green to orange and red as they mature.
Scoville rating: 25,000

Thai peppers (also called: bird chili) have tiny, very hot fruit that turn from green to red at maturity. The fruit are 0.94 cm (0.375 in.) wide by 2.5 cm (1 in.) long. They are used fresh or dried and ground to produce curries.
Scoville rating: 100,000

Wax pepper fruit are yellow when immature and orange-red at maturity. They can be pungent or non-pungent. They vary from 5 to 20 cm (2 to 8 in.) long by 5 cm (2 in.) wide. They are used pickled or fresh.
Scoville rating: 0-5,000

Bell pepper fruit ranges from immature green to a mature (ripened) red, yellow, orange, brown, etc. They are sweet and bell-shaped.
Scoville rating: 0

Eggplants
Eggplant fruit come in a range of shapes and colours. The traditional eggplant produces large, dark purple, pear-shaped fruit. In other types of eggplant, the fruit may be white, cream, mottled or other colours, and they may be short and stubby, long and cylindrical, or other shapes.

Climate and soil requirements

Tomatoes, peppers and eggplants are all warm-season crops and are sensitive to both cool conditions and frost. Extreme heat can also negatively affect growth, reduce fruit set and lead to abnormalities in fruit shape.

These crops grow best at temperatures between 21 and 24°C (70 and 75°F) and tolerate up to 27°C (80°F). They have minimal growth below 18°C (65°F). Eggplants may tolerate somewhat warmer temperatures than peppers and tomatoes.

Place these crops in the field only **after all risk of frost has passed**. Frost protection and growing season enhancement technologies (plastic mulch, row covers, tunnels, etc.) may allow planting dates to be moved up slightly and will promote more uniform, rapid growth over the course of the growing season.

Tomatoes, peppers and eggplants will grow on a range of well drained soil types. Soils should provide some degree of moisture- and nutrient-holding capacity. Soils should have a pH in the range of 5.5 to 7.5.

Planting

These crops must be transplanted to have a chance to mature within the short frost-free season available on the Canadian Prairies. Start tomatoes 6 weeks and eggplants and peppers 8 weeks before the expected date of transplanting into the field.

Approximately 57 to 113 g (2 to 4 oz.) of seed is required to plant 10,000 seedlings. Plant seeds into a sterile growing medium, 6 mm (0.25 in.) deep. Plants may be started in germination trays and then transplanted into larger plug flats or planted directly in the larger containers.

Set germination temperatures at 20 to 25°C (68 to 77°F). Grow seedlings at 18 to 27°C (64 to 81°F) during the day and 15 to 18°C (59 to 64°F) at night. Provide sufficient light and adequate fertilizer to ensure that plants do not become weak and spindly.

Harden off transplants before field setting by withholding water or lowering the growing temperature, as opposed to withholding fertilizer. Plants may be acclimatized by placing them in a sunny but sheltered location for a few days before transplanting.

Place transplants into the field **after all danger of frost has passed**. Plants may also be placed in the field under protection, such as mini tunnels (see the Growing Season Extension section in the Field Production chapter). The use of plastic mulch and other methods can help increase the rate of growth.

Transplants can be hand planted or set with a mechanical transplanter. Transplants should be watered in with a high phosphorus fertilizer solution at or as soon after planting as possible.

Table 35 lists between-row and in-row spacings for field planting of transplants. Plant spacing can vary greatly depending on the size and spread of the plants. Larger, indeterminate types of tomatoes will require a wider spacing between plants and rows. Staked or determinate tomato plants will generally take less space.

Proper plant spacing is important for reducing competition and ensuring good air circulation.

Table 35. Between-row and in-row spacing of tomatoes, peppers and eggplants

Crop transplants	Between-row		In-row	
	(cm)	(in.)	(cm)	(in.)
Eggplants	60 - 120	24 - 48	45 - 60	18 - 24
Peppers	45 - 75	18 - 30	30 - 45	12 - 18
Tomatoes	60 - 180	24 - 72	30 - 70	12 - 27

Fertilizer

ALWAYS base fertilizer applications on the results of annual soil tests. Be careful with the application of nitrogen, especially in tomatoes, as too much nitrogen (N) will cause excessive vegetative growth, delayed maturity or lack of fruit set.

In general, broadcast and incorporate the following before planting:

- 39 to 77 kg N/ha (35 to 70 lb. N/ac.)
- 149 to 176 kg P/ha (135 to 160 lb. P/ac.)
- 127 to 165 kg K/ha (115 to 150 lb. K/ac.)
- 28 kg S/ha (25 lb. S/ac.)

Reduce the rates of phosphorus and potassium to one-fifth and one-half, respectively, if side-banded.

An application of phosphorus fertilizer (liquid or granular) should be made at transplanting.

Irrigation

Tomatoes, peppers and eggplants require a steady, uniform supply of water throughout the growing season. Irrigation is a critical component in producing a high quality crop.

Any interruption in moisture uptake (e.g. due to drought) can significantly reduce fruit quality, due to the development of physiological disorders such as blossom end rot (BER), which is caused by uneven calcium uptake.

In general, about 25 mm (1 in.) of moisture (including precipitation) should be applied per week. The critical moisture periods are during flowering, fruit set and enlargement.

Insect pest management

Colorado potato beetle (*Leptinotarsa decemlineata*)

Description/life cycle

The adult Colorado potato beetle (CPB) is a largish leaf beetle about 10 mm (0.4 in.) long and 8 mm (0.3 in.) wide. It has a dark brown head and thorax and an abdomen with 10 longitudinal stripes on a yellow-cream elytra.

Larvae are dark to bright red with rows of black spots. A single, complete generation per season is typically observed in the Prairies. Adults typically emerge in June, and larvae are present in late June, July and possibly early August, with adults appearing again later in August. For more details, see Colorado Potato Beetle in the Potatoes section.

Damage/symptoms

Damage can be severe with adults or larvae completely defoliating plants, notably seedlings. Direct feeding may also damage fruit.

Control/management

Chemical control, physical removal or row covers are all viable control options, depending on the operation's scale. If chemical control is chosen, resistance management must be considered when selecting insecticides.

Cutworms (various species)

Cutworms, particularly climbing types, have been reported to be problematic in tomatoes in some provinces. For more information on cutworm life cycle, damage and management, see Common Insect Pests of Vegetable Crops in the Insect Pest Management section of the Pest Management chapter.

Disease management

Bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*)

Description/disease cycle

The bacterial canker bacterium may survive on crop residues for 5 years. Inoculum may come from plant debris, infected weeds, diseased transplants, infested seeds and even contaminated wooden stakes.

When transplants are produced, the action of clipping the plants to develop sturdier plants can spread the bacterium from plant to plant if it is present. The pathogen can also be spread by shipping infected plants that are not showing any symptoms.

Symptoms may not show up for a month after planting in the field. Transplanting infected plants can also lead to the spread of the bacterium to equipment, personnel and previously uninfected plants. Splashing water from rain and sprinkler irrigation can also spread the bacterium.

Infection occurs through wounds on leaves, broken leaf hairs, stomates (pores) and leaf edge hydathodes (leaf tissue that secretes water). The bacterium can then develop systemically, making its way into the vascular system and spreading throughout the plant.

Disease development is favoured at temperatures between 24 and 32°C (75 and 90°F) along with conditions that create succulent tissue growth in the plants.

Tomatoes, peppers, eggplants and black nightshade can be infected by this pathogen.

Damage/symptoms
Lower foliage is usually affected first, with curling, chlorotic leaves as the initial symptom, followed by browning, dead tissues. The foliar symptoms typically appear on one side of the leaf, while the other side of the leaf appears healthy.

Bacterial canker lesions of brown, necrotic tissue
Photo: L. MacDonald, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Infected vascular tissues first turn light yellow to tan, and later turn reddish brown. Pith tissues take on a mealy texture and separate from the adjacent vascular tissue, resulting in hollowing of the stem centres.

Control/management
Inspect transplants and remove any suspect plants and surrounding transplant trays. Sanitize and decontaminate benches, trays and any equipment that comes in contact with the plants. If transplants are mowed to manage the height, sanitize the mower before and after use, recognizing that a contaminated mower can spread the bacteria through the field.

Transplant seedlings only when the foliage is dry. Avoid overhead irrigation. Do not enter fields when they are wet.

Sanitize tools that are used in the field frequently. Avoid the use of used wooden stakes or steam the stakes to kill any contaminating bacteria.

If the disease is at a low level in the field, consider roguing (removing/culling) infected plants and probably any immediately adjacent plants, if practical. Turn under any crop debris after harvest. Rotate to a non-host crop. Eliminate any volunteers or weed hosts.

Black mould (*Alternaria alternata*)

Description/disease cycle
Black mould only affects ripened fruit. Losses may be substantial under conditions suitable for disease development.

Alternaria alternata is frequently found on decomposing plant material near fields, including old tomato foliage of the current crop. This fungus is an opportunist, infecting fruit damaged due to sunscald or blossom end rot. Fruit that is kept wet may also develop the disease. Temperatures between 24 and 28°C (75 and 82°F) are optimal for disease development.

Damage/symptoms
Initial symptoms appear as small, tan to brown stains on the cuticle of the fruit. These infected areas increase in size to become large, sunken, round lesions that extend deep into the tissues of the fruit. Black masses of spores can cover the lesion surfaces, and decay by *Alternaria alternata* and other decay organisms can follow.

Control/management
Harvest fruit promptly once ripe to avoid leaving them in the field for excessive periods. Do not irrigate from overhead as this action will wet the fruit, potentially increasing the risk of infection.

Blossom end rot (physiological disorder)

Description
Blossom end rot (BER) gives the appearance of a disease or insect problem, but it is a physiological disorder of the fruit. This problem can occur on peppers, eggplants and, most severely, on tomato.

This disorder is caused by insufficient calcium when the fruit are developing. Changes in water supply, from near drought conditions to heavy rain showers, or uneven watering practices contribute to the development of this disorder.

In addition to drastic changes in moisture, calcium deficiencies can also result from excessive nitrogen fertilization, rapid plant growth and root pruning during cultivation.

Damage/symptoms
Symptoms can occur on any stage of growth. On green fruit, light brown flecks and then lesions aggregate at the blossom end of the developing fruit. These areas begin to darken to brown or black and are round to oval. Decay organisms can colonize the damaged tissues and lead to rotting of the fruit.

Blossom end rot
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Tomatoes also have an internal fruit symptom that can appear as areas of grey tissue with a distinct purple to brown margin.

Control/management
Manage BER through cultural practices. It is critical to maintain uniform soil moisture throughout the season by irrigating plants regularly with an appropriate amount of water. Avoiding damage to roots is also important. By ensuring uniform water supplies and healthy roots, the calcium uptake can be stabilized.

The application of calcium fertilizers, such as calcium chloride or calcium nitrate sprays, may help prevent BER in some situations, but may be ineffective in many cases.

Once symptoms begin to appear, it is impossible to fix the damaged tissues.

There can be differences in susceptibility of different cultivars, but this trait is not typically tested for. If a cultivar consistently has problems with BER in a particular production area, it may be worth considering alternatives.

Early blight (*Alternaria solani*)

Description/disease cycle
Found virtually everywhere tomatoes are grown, early blight can be devastating if left unmanaged. Areas subject to frequent dew development are generally the areas most affected by early blight.

This pathogen also affects potato. Pepper and eggplant usually do not develop this disease.

The fungus can overwinter on crop debris and can persist for at least a year. Infected seed can also introduce the pathogen to an area. Volunteer tomato plants, potatoes and black nightshade (*Solanum nigrum*) can also develop the disease.

Spore production is quite rapid, and spores can be wind-blown for kilometres. Disease development is favoured by abundant moisture and temperatures of 24 to 29°C (75 to 84°F). Multiple cycles of disease can occur within a season.

Damage/symptoms
Fruit, stems and leaves of tomato can all develop symptoms. Infection can occur as early as the seedling stage, but typically, the disease is found on older plants. Dark spots may occur on the cotyledons, stems and true leaves. At the seedling stage, leaves may be killed and stems may be girdled.

On mature or established plants, the symptoms appear initially as small, dark brown or black round spots on older leaves. Sometimes, the spots have yellow halos. These small spots grow into lesions about 1 cm (0.4 in.) wide, with concentric rings within the lesion. Lesions are contained by the veins; by contrast, lesions caused by late blight, a similar disease, are not contained (see Late Blight in the Tomatoes, Peppers, Eggplants section).

The affected leaves may die prematurely, leading to defoliation. The loss of leaves can expose the developing fruit to direct sunlight, resulting in sunscald (see Sunscald in the Tomatoes, Peppers, Eggplants section) and poor fruit colour. Lesions on stems appear elongated, with concentric rings.

Fruit infections can appear as spots on green or ripened fruit and generally develop at the stem end first. Lesions appear as tough, sunken areas with a concentric ring pattern similar to that observed on leaves and stems.

Control/management
Use resistant or tolerant cultivars, if they are suitable and available. Use disease-free seed, or treat the seed with hot water or a registered seed treatment.

Use a long crop rotation, particularly one that includes cereals and legumes. Plough under any crop debris immediately after harvest. Control volunteer tomatoes, potatoes and solanaceous weeds such as nightshade. Fertilize the plants appropriately to keep growth healthy.

Scout fields regularly for symptom development, especially from 2 to 6 days after a rainfall. A regular fungicidal spray program of 7 to 14 days may be necessary, especially if early blight has been reported in the area.

Grey mould, ghost spot (*Botrytis cinerea*)

Description/disease cycle
Grey mould is a common disease of many vegetables, including tomatoes, peppers and eggplants. Symptoms can vary with the cultivar, affected plant part and growth conditions. Damage can range from devastating to minor, insignificant blemishes. Grey mould can be very damaging in humid greenhouse environments.

The pathogen can survive on crop debris, weed plants and sclerotia in the soil. Production of wind-borne conidia helps disperse the pathogen. The pathogen often exploits wounds and senescing tissue in the host. All above ground plant tissue is susceptible. Free moisture on wounded tissue can lead to the rapid development of the disease.

Damage/symptoms
The grey, fuzzy appearance of grey mould is the most recognizable characteristic of the disease.

Lesions can expand rapidly to cover a leaflet, an entire leaf and eventually a stem. Lesions may girdle the stem, resulting in the death of all growth above the lesion. Any fruit that is in contact with the diseased foliage may begin to rot.

Spreading foliar lesions of grey mould
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

"Ghost spots" on tomato caused by grey mould
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Senescing petals can also become infected. Because they can remain present as fruit develops, infected petals that touch the fruit can allow the fungus to grow into the young fruit. Symptoms are often observed at the blossom end of the fruit.

On fruit, lesions may appear as decayed, white areas. The skin often ruptures in the diseased area, and eventually, the whole fruit may dry out and mummify.

Another symptom is "ghost spot," which is essentially an infection that stopped due to high temperatures at the fruit surface. The infection does not progress to cause any damage due to decay, but does decrease market value. The symptom consists of a white to yellow-coloured ring up to 1 cm (0.4 in.) in diameter.

Control/management
Reduce moisture on plants by avoiding the use of overhead sprinkler irrigation. In greenhouses, ensure adequate ventilation or heat to reduce the humidity.

The use of registered fungicides, both in the greenhouse and the field, is often necessary, as the disease can spread rapidly.

Late blight (*Phytophthora infestans*)

Description/disease cycle
As with early blight, both tomato and potato are susceptible to the late blight pathogen (*Phytophthora infestans*). Other potential hosts, such as eggplants, peppers, solanaceous weeds (e.g. nightshades) and petunia, may be occasionally affected. Some strains of the fungus are potentially more devastating to tomato than potato and vice versa.

Under suitable conditions this pathogen can cause severe crop losses, and if left unmanaged, complete crop loss could occur. Late blight occurs infrequently on the Prairies; however, occurrence of the disease appears to be increasing. Spread of the pathogen by infected transplants has posed problems in recent years.

On the Canadian Prairies, this fungus does not form an overwintering spore type. The pathogen will only survive and overwinter on living host tissues. Initial sources of inoculum could be from infected seed potatoes and/or cull piles with infected tubers. Late blight is **not carried** on tomato seed.

Within the growing season, spores can travel many kilometres on storm fronts, blown from nearby potato or tomato plantings, or infected transplants can introduce the pathogen.

Cool, wet conditions favour disease development. Moisture is necessary for spore production and germination as well as for the movement of spores on plants and within the soil. Sporangia are produced, which can penetrate the plant directly or germinate to form mobile zoospores. Spores can be splashed or washed onto foliage.

Damage/symptoms
Symptoms appear on foliage and fruit. Irregularly shaped, greasy-appearing grey-green areas develop on leaves, and the entire leaf may be destroyed. Lesions spread aggressively across the leaf surface and are not contained by the leaf veins. Under suitable conditions, a velvet white growth may occur on the underside of the leaf at the lesion margins. Lesions on stems and petioles may appear water-soaked and later grey. Colonization by the fungus can occur rapidly, killing entire plants.

Green-brown lesions on fruit caused by late blight
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Close-up of late blight lesions on tomato leaves
Photo: D. Burke

Late blight tissue dieback
Photo: Tom Gonsalves

Fruit infections appear as round to oval, irregularly shaped lesions that are olive to brown. Lesions can cover much of the fruit's surface. These lesions are usually firm as opposed to soft. The possibility of further breakdown may occur as other decay organisms attack the fruit.

Control/management
If the disease is present or if conditions favour disease development, regular fungicide applications at 5- to 10-day intervals are necessary.

Aggressively dispose of all infected plant material as soon as it is detected. Diseased material should be buried or frozen. Do not leave it in piles, as dying tissues can still produce plenty of spores to infect healthy plants. Eliminate cull piles of potatoes, as well as any volunteer solanaceous plants (e.g. potatoes, tomatoes, eggplants, peppers, petunias) and solanaceous weeds (e.g. nightshades).

Carefully inspect all solanaceous transplants, as the disease can develop in greenhouses, particularly in other regions where late blight is common.

Avoid the use of overhead irrigation if possible because this practice can disperse the pathogen. Ensure good plant spacing and adequate air movement within the canopy to keep relative humidity at a lower level.

Very few resistant cultivars are available.

Sunscald (physiological disorder)

Description
Sunscald is caused by sudden exposures to direct sunlight, usually during hot, dry weather. Fruit are typically injured to the greatest extent, but leaves and stems may also be affected. The loss of foliage for a number of reasons exposes tender portions of the plant to direct sunlight.

Diseases that defoliate (such as early blight, septoria leaf spot or wilt diseases), excessive heat, insect feeding or cultural practices that alter the canopy rapidly could all contribute to the development of this disorder.

Damage/symptoms
Symptoms can appear on the tissue exposed to the sun on green or ripened fruit. Initially, the affected areas appear sunken and white to cream. This damaged tissue may begin to appear olive, brown or black due to the activities of decay organisms, which can lead to further decay.

Sunscald damage in pepper
Photo: D. Ormrod, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Leaf and stem tissue damage typically occurs early in the season, with exposed stems turning white and leaf surfaces having irregularly shaped bands.

Control/management
Any practice that keeps the foliage healthy is beneficial because the foliage can help shade the developing fruit.

Verticillium wilt (*Verticillium albo-atrum*, *Verticillium dahliae*)

Description/disease cycle
Verticillium wilt can affect a range of host crops, including potatoes, tomatoes, eggplants, peppers, solanaceous weeds, cucurbits and some fruit as well as ornamental crops.

This disease can be caused by either of two species of *Verticillium*. The fungi are soil-borne. Each species has different climatic preferences, which can determine the species causing the disease that develops; however, both species may be in the soil.

These pathogens overwinter and survive in the soil on crop debris either as microsclerotia (*Verticillium dahliae*) or mycelium (*Verticillium albo-atrum*). Roots of host plants become infected, and the pathogen develops systemically via the xylem vessels.

Damage/symptoms
Initial symptoms are yellowing of the foliage, and then, the plant begins to wilt. Lesions may be yellow and v-shaped, with the wider portion at the leaf margin and the inner part of the lesion turning brown and necrotic. Lower leaves are affected first. Surrounding leaves may have yellowing without the v-shaped, necrotic lesions. Vascular tissues are brown when stems are cut lengthwise.

V-shaped necrotic lesions characteristic of Verticillium wilt
Photo: Gerald Holmes, Valent USA Corporation, Bugwood.org

Control/management
Maintain at least a four-year rotation between host crops, and implement practices that encourage the breakdown of any crop debris. Control weeds and volunteer plants. Ensure good plant health through adequate fertilization and watering. Resistant cultivars are available for some crops and should be grown if available.

Weed management

The slow, early season growth and relatively wide plant spacings provide lots of opportunities for weeds to become established in these crops. Plastic soil mulches can provide weed control in addition to other benefits. With the wide between-row spacing, weeds may be controlled via tillage or the careful use of long-lasting herbicides.

Control perennial weeds before planting. A decent array of herbicides is available for pre- and post-emergent application, but be aware that not all these crops are registered for all products.

Herbicide injury
Tomatoes are extremely sensitive to damage from the 2,4-D family of chemicals. Take extra care to prevent fumes of these chemicals from drifting onto the crop from neighbouring crop spraying operations. Additionally, very small amounts of residual 2,4-D chemicals can cause significant injury to tomatoes. Pay attention to the use of these herbicides in rotations and their rate of breakdown, which can be influenced by weather conditions.

2,4-D damage in tomato
Photo: I.R. Evans, Vegetable Diseases Image Collection. Western Committee on Plant Diseases. Winnipeg, Man.

Tomatoes (and potatoes) are also very sensitive to other residual herbicides, such as picloram and clopyralid, which can move in soil water or contaminate water sources. Residues can also be found in manure from animals fed straw or other plant material that has been treated with these herbicides.

Use extreme care when selecting and protecting water sources and when using manure or potentially treated soil. Also pay attention to residual chemicals applied in other crops in the rotation, particularly as product labels are expanded. For example clopyralid- and picloram-containing products might be registered for use in commonly grown cruciferous vegetables.

Harvesting

Harvest timing of tomatoes, eggplants and peppers will vary depending on the target market, customer preferences and the crop. In general, all crops should be harvested when fully mature, which will maximize ripeness and flavour. However, the post-harvest lifespan will be shorter for fully ripe fruit.

Harvest eggplants before seed development. The time of harvest varies with the variety and type of eggplant as well as the target market. Quality eggplants should be firm, true to type, uniformly coloured, and free from decay, damage and other blemishes. Over-mature eggplants with obvious dark seeds can be pithy and bitter.

Peppers can be harvested at a range of maturity stages, depending on the type of pepper, the target market and the end use. Bell peppers may be harvested when mature green, or harvest can be delayed until the fruit change colour. Hot peppers (range of types) are harvested when mature.

All peppers should be firm, uniformly shaped (true to type), free from blemishes, decay and damage and should not be wilted. Peppers left on the plant until fully mature should have better flavour development, including increased sugars and compounds that relate to heat.

Tomatoes can be harvested before being fully ripe. Tomatoes generally require multiple harvests, as fruit are set and ripen non-uniformly. Many fruit may not reach full ripeness on the plant. Tomatoes will change colour and soften following harvest, provided they are physiologically mature.

Regardless of harvest timing, fruit should be smooth, turgid, uniform in shape, and free from blemishes, damage and decay.

Post-harvest handling and storage

Tomatoes, peppers and eggplants should be harvested in cool conditions, if possible, and then further cooled immediately after harvest.

Store tomatoes, peppers and eggplants above 7°C (45°F) to prevent chilling injury. Chilling injury may occur in the field, and its effect is carried over to the storage period.

The minimum storage temperature is 10°C (50°F). Mature green tomatoes are more sensitive to chilling than ripe tomatoes; therefore, they should be held at 13 to 16°C (55 to 61°F) until ripe and then cooled to 10°C (50°F). Storage at cooler temperatures may reduce the product's flavour. Relative humidity for the storage of these crops should be kept at 90 to 95 per cent.

Mature green tomatoes can be stored for up to 6 weeks. Ripe tomatoes may only store for a few days. Eggplants can be stored for up to 14 days. Peppers can be stored for 8 to 14 days. Packaging of peppers may extend the storage and shelf life.

APPENDIX

Glossary

Explanations of the terms below are given in the context of technical expressions used in vegetable crop production and are not intended as comprehensive definitions.

Abiotic: relating to non-living, chemical or physical factors

Acclimation: the process of becoming adjusted or hardened to the environment

Acidity: the measure of pH, where values are below 7.0

Active ingredient (AI): that portion of a pesticide formulation toxic to pests. Most pesticide products contain only a portion of active pesticide while the rest is carrier.

Aggregation: the grouping or clustering of similar objects; in soils and insects, the grouping of soil particles or insect populations

Alkalinity: the measure of pH, where values are above 7.0

Allelopathic: relating to a biological phenomenon by which an organism produces one or more biochemicals that influence the growth, survival and reproduction of other organisms

Allowable depletion: the proportion of soil moisture that can be removed by a crop from the soil before the crop begins to experience moisture stress, usually expressed as a percentage of the available moisture in the root zone

Annual: a plant that completes its life cycle from seed through to seed again in a single growing season; a crop that is planted and harvested in one growing season

Apothecium (plural apothecia): the fruit of certain lichens and fungi; usually an open, saucer-shaped or cup-shaped body, the inner surface of which is covered with a layer, called an ascus, that bears spores

Ascospore: a spore that was produced inside an ascus; this kind of spore is specific to fungi classified as ascomycetes

Available moisture: the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point; the amount of water available for use by plants

Bacteria (singular bacterium): very small single-celled micro-organisms that may attack plants and cause disease; bacteria reproduce by cellular splitting

Banding: the placement of fertilizer or pesticide in a continuous band to the side and/or below the seed or the plants

Biennial: a plant that requires two growing seasons to produce flowers and seed – e.g. celery or carrots grown as annuals for fresh crop production but as biennials when grown for seed

Biological controls: methods of controlling pests that use natural or introduced predatory, parasitic or competitive species (e.g. insects, fungi, bacteria)

Biosolids: composted human effluent used as a nutrient source in production

Biotic: of or relating to living organisms

Bolting: premature flowering of a plant. Biennial crops like celery normally produce a seed stalk in their second year. Cold temperatures early in the growing season can cause some types of biennials, such as celery, to bolt or produce a flowering stalk in the first year. Prolonged high temperatures can cause other types of biennials, such as radishes, to bolt.

Bract: a modified or specialized leaf, especially one associated with a reproductive structure such as a flower, inflorescence or cone scale

***Brassica* crops:** vegetables and oilseeds from the Brassicaceae family (e.g. cabbage, cauliflower, etc.)

Broadcast: to spread fertilizer or pesticide over the entire area of the soil surface or the entire crop area

Bulbil: a small bulb or bulb-shaped growth arising from the leaf axil or in the place of flowers

Carrier:

1) an inert material mixed with active pesticide ingredients to make a pesticide formulation, e.g. finely divided clay or talc is used as a carrier in dust forms of insecticides

2) a host infected with a pathogen (e.g. bacterium, fungus, virus) that can transfer the pathogen to a vector – carriers may or may not exhibit disease symptoms

Cation exchange capacity (CEC): a measure of the negative charge on soils (primarily on clays and organic matter), expressed as the quantity of cations (positive ions) that can be adsorbed by the soil

Chemical controls: pest management options involving the application of chemical products that kill or suppress pests or that protect crops from attack

Chemigation: the application of pesticides through irrigation equipment (similar to fertigation)

Chilling injury: physiological damage to plant parts and tissues caused by exposure to low temperatures but not involving temperatures low enough to cause freezing damage – chilling typically damages physiological processes, rather than causing physical damage to tissues

Chlorosis (chlorotic): in plant leaves, a condition where there is insufficient production of chlorophyll, resulting in yellowing of tissues

Cole crops: members of the genus *Brassica*, including cabbage, broccoli, cauliflower and brussels sprouts

Conidia: asexually produced spores

Cotyledon: a seedling leaf in seed-bearing plants, one or more of which are the first leaves to appear from a germinating seed

Coulter: the vertical cutting blade of a seeder that makes the furrow for seed placement

Crown: the centralized region of a plant from which growth is initiated, typically at or near the soil surface

Cruciferous crops: crops within the Brassicaceae family (e.g. cabbage, cauliflower, etc.)

Cucurbits: a general term to describe all members of the Cucurbitaceae family, which includes cucumbers, melons, squash, gourds and pumpkins

Cultivar: a horticultural classification that means cultivated variety. In most cases, cultivars are developed through directed and specific breeding efforts by people, as opposed to naturally occurring or selected plants. The term "variety" is often used (scientifically incorrectly) in crop production to mean cultivar.

Cultural controls: pest management practices that involve manual or mechanical techniques or that relate to suppression or out-competing pests by managing or enhancing crop growth, may also include the use of rotations, varietal selection, etc.

Cuticle: a protective and waxy or hard layer covering the epidermis of a plant

Days-to-harvest/pre-harvest interval (PHI): the period of time stipulated by law that must elapse between time of application of a pesticide and the harvest of the crop

Defoliation: the falling or shedding of leaves

Denitrification: a process in which nitrates are converted to nitrogen gas, usually by microbial activity

Determinate: relating to plants (often bush type) that will not keep growing and that will not produce new blossoms after fruit set, with a limited growth potential

Diapause: a period during which growth or development is suspended

Diatomaceous earth: the ground shells of fossilized single-celled diatoms, which are shelled algae. The material can be used in the control of certain insect pests, as the ground-up product has sharp edges that shred the outer, protective cuticle on insects.

Direct seeded: seeded directly into a field, rather than being grown in a greenhouse and then transplanted

Drift: the undirected and uncontrolled movement of pesticide spray mist that may occur at time of pesticide application, away from the application source and onto non-target areas

Drill: to place fertilizer or pesticide with or near seed in the seed row or furrow

Economic damage threshold: in integrated pest management, the density of a pest at which a control treatment will provide an economic return higher than the treatment cost

Elytra: the protective hardened case that covers an insect's body (mainly wings)

Emulsifiable concentrate: a concentrated pesticide formulation that, due to the presence of an emulsifier, will mix with water to form a fairly stable emulsion (a mix of two products that do not normally dissolve into each other, e.g. oil and water)

Epidermis: the outermost cell layer of plants

Epiphyte: a plant or other organism that grows on another plant but is not parasitic

Exudate: fluid that has been slowly discharged (exuded) from somewhere, especially fluid exuded from a pore or the vascular system of a plant

Fertigation: the process of applying soluble fertilizer materials through an irrigation system

Fertilizer: any material added to soil or crops that is a source of plant nutrients, may be organic, inorganic or synthetic

Field capacity: the maximum amount of water a particular soil can hold, depends on soil texture

Fluming: the process of using an artificial channel or trough (flume) for conducting water, to transport objects (e.g. produce) from one area (e.g. bulk storage) to another area (e.g. washing equipment)

Foliar: of, pertaining to, or via the leaves

Frass: the droppings or excrement of insects

Frost-free period: the time between the last spring frost and the first fall frost – essentially, this time determines the length of the growing season of frost-sensitive plant species in an area

Fumigation: the use of pesticides in a gas form to destroy pests

Fungi (singular fungus): organisms of the kingdom Fungi, feeding on organic matter, ranging from unicellular to multicellular organisms and lacking roots, stems, leaves and chlorophyll. Some species of fungi are parasitic and attack living plants. Soil fungi aid in the breakdown of organic matter.

Fungicides: chemical compounds or biological organisms used to kill or inhibit fungi or fungal spores

Germination:

1) the beginning of the growth processes of a seed or spore once it is placed into suitable moisture and temperature conditions

2) the proportion of plant seeds that will germinate, expressed as a percentage

Graded or sized seed: seed that is sorted within a close range of minimum and maximum sizes. The narrow size range of seed is required by precision seeders. Note: all seed is graded to remove weed seeds, poor seed and impurities.

Granular pesticide: a pesticide formulation made of relatively coarse particles that is applied dry with a spreader, seeder or special applicator

Green manure: a crop that is grown and ploughed down, typically before reaching maturity, to serve as a source of organic matter for the soil

Hardening off: the practice of preparing tender, indoor-grown seedlings for field conditions, by withholding water or nutrients by or lowering temperature or by exposure to increased air movement

Herbicide: a pesticide used to kill or inhibit the growth or development of weeds

Herbigation: the process of applying herbicides through an irrigation system

Host crop: a crop that can be infected or that serves as a "host" for an organism during its lifecycle.

Humus: that part of soil organic matter in the final stages of decomposition that is normally slow to be totally broken down, both physically and chemically, because of its chemical composition and structure

Hydathode: a type of secretory tissue in leaves of some plants that secretes water through pores in the epidermis or margin of leaves, typically at the tip of a marginal tooth or serration

Hydro-cooling: a method of rapid cooling accomplished by immersing fresh produce in very cold water

Hypocotyl: the part of the stem of an embryo plant beneath the stalks of the cotyledons and directly above the root

Incorporate: to uniformly and thoroughly mix a pesticide, fertilizer or crop debris into the soil to a specified depth

Indeterminate: relating to plants that will keep growing and producing new blossoms even after fruit set, means plants have potentially unlimited growth

Inoculant (verb inoculate): organisms or agents that promote immunity against disease or that stimulate activity, such as nodule formation, when introduced into an organism or medium; may be used in either disease or fertility management applications (e.g. nodulation for nitrogen fixation in legume crops)

Inoculum: a pathogenic structure (e.g. spore, mycelium, sclerotium, etc.) that induces disease

Insecticide: any chemical substance used to kill, harm or repel unwanted insects

Instar: a developmental stage of insects, between each moult, until sexual maturity is reached

Integrated pest management (IPM): a broad interdisciplinary approach using scientific principles of crop protection fused into a single system using a variety of methods and tactics; the use of multiple methods to minimize the effect of pests, taking into consideration economic thresholds and the effect of pests

Internode: a part of a plant stem between two of the nodes or joints from which leaves emerge

Larva (plural larvae): a growth stage for some insects; the stage at which they are wingless and resemble a caterpillar or grub after hatching from the egg

Leaf stage: a stage of development of a crop or weed species, typically used to determine the timing of chemical applications for maximum efficacy (e.g. one-, two- or three-leaf stage)

Lenticels: small pores on the stem and root surfaces of vascular plants that allow gas exchange to take place

Macronutrient: an essential mineral nutrient required by plants in large amounts

Microclimate: local atmospheric zone where the climate differs from the surrounding area. The term may refer to areas as small as a few square feet (e.g. a garden bed) or as large as many square kilometres (e.g. a valley). Microclimates may occur naturally or may be created by the grower.

Microclimate modification: techniques or methods applied to a localized area to modify the effect of the climate to improve growth and productivity; modifications may relate to the soil, the above ground environment or both

Micronutrient: an essential mineral nutrient required by plants in relatively small amounts

Micro-organism: a very small organism (individual part) difficult or impossible to see with the unaided eye, such as a virus or bacterium

Mineralization: the process in which an organic (carbon-based) substance is converted to an inorganic substance (e.g. organic forms of nitrogen are converted to plant-available inorganic forms)

Miticide: a pesticide formulated specifically to kill, harm, repel or mitigate one or more species of mites

Mulch: a protective cover placed over the soil, primarily to modify the effects of the local climate. A wide variety of natural and synthetic materials are used as mulches.

Mustard family: a large family of plants with four-petaled flowers, also called cruciferous crops or *Brassica* crops; Brassicaceae or Cruciferae

Mycelium: the vegetative part of a fungus, consisting of a network of fine white filaments (hyphae)

Necrosis (necrotic): the death of most or all the cells in a plant tissue due to disease or injury; a form of cell injury

Nematicide: any pesticide designed to control nematodes

Nematode: very small, worm-like organisms in a variety of environments, usually a parasite. Some nematode species may cause severe crop damage by attacking and living in plant tissues. Normal nematode sizes range from 0.8 to 3 mm (1⁄32 to 1⁄8 in.).

Nitrogen fixation: a process by which nitrogen (N_2) in the atmosphere is converted into ammonia (NH_3) by nitrogen-fixing micro-organisms

Nocturnal: active during the night and inactive during the day

Nutrient: a chemical element required for growth; plant growth requires 17 essential elements

Nymph (nymphal): the immature stage of certain species of insects. Nymphs usually resemble the adults but are typically smaller and lack wings.

Organic:

1) relating or belonging to the class of compounds having a carbon basis
2) of or relating to product grown without synthetic fertilizers or pesticides

Organic matter (OM): plant or animal residues in varying stages of decomposition. Undecomposed plant material is normally referred to as crop debris, crop residue or trash; it is not called organic matter until the material starts to break down.

Osmotic potential: the pressure that needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane; the minimum pressure needed to stop osmosis

Oviposit (oviposition): the process of egg laying in insects, using a specialised organ called an ovipositor

Parasite: an animal or plant that lives in or on a host; obtains nourishment from the host without benefiting or killing the host

Parasitoid: an organism that lives at the expense of its host, impeding its growth and eventually killing it

Pelleted seed: seed coated with clay, vermiculite or other substances to form uniform round or oval pellets. Irregularly shaped seeds such as carrot and lettuce seed can be coated so that they can be seeded more accurately with precision seeders.

Periderm: the corky outer layer of a plant stem formed in secondary thickening or as a response to injury or infection

Permanent wilting point: the minimum amount of moisture in the soil that the plant requires to not wilt

Pest:

1) an organism such as an insect, fungus or weed that harms or competes with crop plants
2) a destructive insect or other animal that attacks crops, food, livestock, etc.

Pesticide: any substance or mixture of substances intended for preventing, destroying, repelling or mitigating a pest

Petiole: the slender stem that supports the blade of a leaf

pH: a figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acidic, and higher values are more alkaline

Phloem: the living plant tissue responsible for carrying sugars produced during photosynthesis throughout the plant

Physiological maturity: the developmental stage at which a fruit or other product reaches true maturity, a point beyond which no further size increase should occur, and further development is merely ripening, colour changes and increases in sugars, flavour compounds, etc. This stage is not necessarily considered ripe, particularly in fruit such as tomatoes.

Phytoplasma:

1) specialised bacteria that are obligate parasites of plant phloem tissue and transmitting insects (vectors)

2) bacteria-like organisms, some of which cause plant diseases

3) disease-causing agents similar to viruses

Plasticulture: the practice of using plastic materials as a means of microclimate modification, resulting in improved yields and crop quality

Post-emergence (POST): after a crop emerges from the soil; often used in relation to pesticide application timing

Post-harvest handling: the various stages of handling a harvested crop after harvest and before use, including washing, drying, curing, sorting, grading, trimming, packaging, cold storage, etc.

Potable: water that does not contain pollutants, contaminants, objectionable minerals or infective microbes and is considered safe for drinking

Precision seeder: a type of seeder designed to accurately place a single seed at a uniform spacing and uniform depth in the row

Pre-emergence (PRE): the time after planting seed but before a crop emerges; often used in relation to pesticide application timing

Pre-plant incorporated (PPI): a pre-emergent herbicide applied to the soil (as a spray or broadcast granular product) and then incorporated into the soil using tillage or irrigation to form a uniform barrier to weed emergence in the soil

Pupa (plural pupae) (verb pupate): an insect in the inactive stage of development (when it is not feeding), intermediate between larva and adult

Pycnidium (plural pycnidia): an asexual fruiting body produced by certain types of fungi, which produces spores

Re-entry interval (REI): the minimum time stipulated by law that must pass between the time of spraying a pesticide and the time when the area may be entered by people, unless protective clothing and breathing aids are used

Relative humidity (RH): moisture content in the air, expressed as a percentage of the amount of moisture the air would hold if fully saturated with moisture

Residue:

1) the portion of a pesticide or fertilizer that remains in the soil or on crop plants after application. Amounts of residue decrease with time. Pesticides may leave residues that last from hours to years.

2) crop debris remaining in the field after harvest

Residue tolerance: the maximum amount of a pesticide residue that may lawfully be present in or on a food product offered for sale. The tolerance amount is expressed in parts per million (ppm).

Rhizome: a horizontal plant stem with shoots above and roots below, serving as a reproductive structure

Rogue: the process of searching for and removing undesirable, unsuitable or infected (with a pest) plant material from a plant population, often to protect the crop from further spread or development of a pest

Saprophyte (saprophytic): a plant, fungus or micro-organism that lives on dead or decaying organic matter

Scape: a flowering stem, usually leafless, rising from the crown or roots of a plant; associated with bulbs

Sclerotium (plural sclerotia): hard, dark resting body of certain fungi, consisting of a mass of hyphal threads and capable of remaining dormant for long periods

Scouting: the action of systematically visiting and examining fields and individual plants on a regular basis to detect, measure and track the development of pest species; linked to integrated pest management

Seed treatment: chemical or physical treatment of seed to eliminate or reduce organisms that may cause seed decay, seedling death or disease in a growing crop. Chemical treatments include fungicide and insecticide applications to the seed. Physical treatments include briefly immersing seed in hot water.

Senescence:

1) the cessation of cellular division

2) the condition or process of deterioration with age

Side-dress: to apply fertilizer in the soil alongside a crop row after the crop is established

Sized seed: see graded seed

Skeletonization: a type of insect damage characterized by feeding on leaf areas between leaf veins

Soil amendment: a material, such as organic matter or sand, mixed into soil to improve growing conditions

Soil pH: a measure of soil acidity or alkalinity; the logarithmic expression of the activity of hydrogen ions in the soil solution expressed in a 0 to 14 scale

Solanaceous: of or relating to plants of the Solanaceae family (nightshade or potato family)

Specific gravity (SG): the density of a substance relative to the density of water; in potatoes, SG relates to density and dryness of the potato flesh

Spiracles: minute pores distributed over the surface of an insect's body that serve as entrances to the respiratory system

Sporangium (plural sporangia): a structure containing the spores of fungal species

Spore: a reproductive structure adapted for dispersal and survival for extended periods in unfavourable conditions; part of the life cycle of many organisms, particularly fungi

Sporulation: the process of producing spores

Spreader sticker: an additive used to improve the efficiency of a pesticide formulation. It may have properties that aid the spreading of a liquid over the leaf and plant surface. It may also enhance the ability of the particles to adhere to the plant surfaces.

Stale seedbed: a weed management practice where non-selective herbicides are applied to control weeds that have emerged after a crop has been seeded, but before the crop emerges

Starter solution: a solution made up of water and water-soluble fertilizer applied at the time of transplanting to meet the early nutrient requirements of transplants. These solutions usually contain an abundance of phosphorus to promote root growth.

Stele: the central core of the stem and root of a vascular plant, consisting of the vascular tissue (xylem and phloem) and associated supporting tissues

Sterilization: a process of treating material (soil, growing media, equipment or tools) to kill fungi, bacteria, weed seeds and other organisms that may be harmful to the crop or the consumer

Stolon: a shoot that grows along the ground and produces roots at its nodes

Stomate (also called stoma, plural stomata): a minute epidermal pore in a leaf or stem through which gases and water vapour can pass

Suberin (verb suberize): a waxy, waterproof substance that occurs naturally in the cell walls of cork tissue in plants. It acts together with other compounds to protect plant surfaces from water loss and microbial attack, and also helps to close tears and breaks.

Surfactant: a compound that increases the spreading ability of a liquid (e.g. emulsifiers, soaps, wetting agents, detergents and spreader stickers) and aids in the effectiveness of some herbicides and insecticides. Do not use any surfactants unless they are recommended by pesticide manufacturers.

Systemic pesticide: a pesticide that is absorbed by and flows through the internal system of a plant or animal so that the entire plant or animal becomes toxic to the pest to be controlled

Teliospore: the thick-walled resting spore of some fungi (rusts and smuts), from which the basidium (club-shaped spore-bearing structure) arises

Tensiometer: an instrument for measuring the moisture content of soil; measuring soil moisture tension

Thorax: the part of an insect's body that bears the wings and legs

Top-dress: to apply fertilizer by broadcasting to the entire growing area after a crop is established

Toxicity: the poisoning ability, in speed and severity, of a substance. The toxicity of a chemical to humans is usually based on its assumed (or known) effect on humans and its known effect on test animals.

Translocate: the transport of dissolved material within the vascular system of a plant

Transplanting: the movement or re-planting of plants from one growing area or growing environment to another. In vegetable crop production, some long-season crops are started in greenhouses and transplanted into the field, thus extending the growing season.

Turgid (turgor): the condition of a cell, tissue or plant when it is filled with water so that it is firm; not wilted

Variety: a taxonomic category consisting of members of a species that differ from others of the same species in minor but heritable characteristics. Broccoli, cabbage and cauliflower are varieties of one species of plant. The term variety is commonly misused interchangeably to mean cultivar (cultivated variety).

Vascular ring: the vascular area of a potato tuber, which is arranged in a ring near the surface of the tuber

Vector: an organism that transmits a pathogen from reservoir to host

Vegetative propagation: a type of asexual reproduction for plants; a process by which new plant "individuals" arise or are obtained without the production of seeds or spores

Virus (viral): a submicroscopic organism consisting of nucleic acid and protein. All plant viruses are parasitic.

Volatilization (volatility): the evaporation (release of fumes) of pesticides (or any liquid or solid) after landing on the target plant; also known as evaporation

Weed: a plant growing where it is not wanted

Wettable powder: dry formulation of a pesticide that is normally mixed with water to form a sprayable suspension

Wetting agent: see surfactant

Windrowing: a process used in some harvesting systems where the harvested product is placed in a row or grouped on the soil surface, locations from which it is later harvested. Windrowing may be used as a pre-harvest practice to allow the harvested produce to dry and cure somewhat before storage (e.g. onions, garlic).

Xylem: the vascular tissue in plants that conducts water and dissolved nutrients upward from the root

Resources

1.1 Industry Resources

1.1.1 Provincial Grower Association Contact Information

Alberta
Alberta Farm Fresh Producers Association
Box 20, Site 3, RR 1
Okotoks, AB T1S 1A1
Telephone: 1-403-558-0189
Website: www.albertafarmfresh.com

Saskatchewan
Saskatchewan Vegetable Growers Association
Box 1121
Outlook, SK S0L 2N0
Website: www.svga.ca

Manitoba
Vegetable Growers Association of Manitoba
Box 894
Portage La Prairie, MB R1N 3C4
Telephone: 204-857-4581
Fax: 204-239-0260
Website: www.vgam.ca

1.1.2 Provincial Government Contacts

Alberta Agriculture and Rural Development (ARD)
ARD General Contacts
E-mail: duke@gov.ab.ca
Website: www.agriculture.alberta.ca

Alberta Ag-Info Centre
Commercial Horticulture Specialist
Postal Bag 600
4705 49th Ave
Stettler, AB T0C 2L0
Toll-free: 310-FARM (3276)
Out of province: 403-742-7901
Fax: 403-742-7527

New Venture Specialist
310-FARM (3276)

Business Development Specialist – Horticulture Crops
17507 Fort Road NW
Edmonton, AB T5Y 6H3
Telephone: 780-415-2304
Fax: 780-422-6096
Email: belinda.choban@gov.ab.ca

Saskatchewan Ministry of Agriculture
Saskatchewan Agriculture Knowledge Centre
45 Thatcher Drive East
Moose Jaw, SK S6J 1L8
Toll-free: 1-866-457-2377
Fax: 306-694-3938
Toll-free Fax: 1-800-775-5358
Out-of-province: 306-694-3727
E-mail: aginfo@gov.sk.ca
Website: www.agriculture.gov.sk.ca/ask_saskatchewan_agriculture

Provincial Specialist, Vegetable Crops
Crops Branch
Saskatchewan Ministry of Agriculture
Room 125, 3085 Albert Street
Regina, SK S4S 0B1
Telephone: 306-787-2755
Fax: 306-787-0428
Email: connie.achtymichuk@gov.sk.ca

Manitoba Agriculture, Food and Rural Development
Business Development Specialist – Vegetable Crops
Crops Knowledge Centre
Box 1149
Carman, MB R0G 0J0
Telephone: 204-745-5675
Fax: 204-745-5690
E-mail: tom.gonsalves@gov.mb.ca

Farm Production Extension Pathologist
Crops Knowledge Centre
Box 1149
Carman, MB R0G 0J0
Telephone: 204-745-0260
Fax: 204-745-5690
E-mail: vikram.bisht@gov.mb.ca

1.1.3 Federal Government Resources

Pest Management Regulatory Agency
www.hc-sc.gc.ca/ahc-asc/branch-dirgen/pmra-arla/index-eng.php

Pesticide Label Search Engine
http://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php

Canadian Food Inspection Agency
www.inspection.gc.ca

1.1.4 Vegetable Research Programs (Prairie)

Saskatchewan
University of Saskatchewan – Vegetable Program
Dr. Doug R. Waterer, Associate Professor
Department of Plant Sciences, College of Agriculture
University of Saskatchewan
51 Campus Drive
Saskatoon, SK S7N 5A8
Telephone: 306-966-5860
Fax: 306-966-5015
E-mail: doug.waterer@usask.ca
Website: www.usask.ca/agriculture/plantsci/vegetable/

University of Saskatchewan - Plant Pathology
Dr. Jill Thomson
Department of Biology, College of Arts & Science
University of Saskatchewan
112 Science Place
Saskatoon, SK S7N 5E2
Telephone: 306-966-4243
Fax: 306-966-4461

Manitoba
University of Manitoba – Plant Pathology
Dr. Fouad Daayf
Dept. of Plant Sciences
222, Agriculture Building
University of Manitoba
Winnipeg, MB R3T 2N2
Telephone: 204-474-6096
Fax: 204-474-7528
E-mail: daayff@ms.umanitoba.ca
Website: www.umanitoba.ca/afs/plant_science/

Canada/Manitoba Crop Diversification Centre
P.O. Box 309
Carberry, MB R0K 0H0
Telephone: 204-834-6000
Fax: 204-834-3777
Website: www.agr.gc.ca/eng/about-us/offices-and-locations/canada-manitoba-crop-diversification-centre/?id=1185205367529

1.1.5 Irrigation

Agri-Environment Services Branch
Canada-Saskatchewan Irrigation Diversification Centre
901 McKenzie Street, South
P.O. Box 700
Outlook, SK S0L 2N0
Telephone: 306-867-5400
Fax: 306-857-9656
E-mail: csidc@agr.gc.ca
Website: www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186153747182

1.1.6 Shelterbelts

Agri-Environment Services Branch
Agroforestry Development Centre (formerly Shelterbelt Centre)
P.O. Box 940
Indian Head, SK S0G 2K0
Toll-free: 1-866-766-2284
Fax: 306-695-2568
Website: www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186517615847

Agri-Environment Services Branch Locations (by region)
www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187362338955&lang=eng

1.2 Water and Soil Resources

1.2.1 Soil/Water Testing Laboratories

Agvise Laboratories
604 Hwy 15 West
P.O. Box 510
Northwood, ND 58267
Telephone: 701-587-6010
Fax: 701-587-6013

902 - 13 Street North
P.O. Box 187
Benson, MN 56215
Telephone: 320-843-4109
Fax: 320-843-2074

A&L Canada Laboratories
2136 JetStream Rd.
London, ON N5V 3P5
Telephone: 519-457-2575
Toll-free: 1-855-837-8347
Fax: 519-457-2664
Email: alcanadalabs@alcanada.com

ALS Laboratory Group
Alberta
5424 - 97 Street
Edmonton, AB T6E 5C1
Telephone: 780-391-2300

9505 - 111 Street
Grande Prairie, AB T8V 5W1
Telephone: 780-539-5196

245 MacDonald Crescent
Fort McMurray, AB T9H 4B5
Telephone: 780-791-1524

Saskatchewan
819 - 58 Street East
Saskatoon, SK S7K 6X5
Telephone: 306-668-8370

1119 Osler Street
Regina, SK S4R 8N5
Telephone: 306-668-8370

Manitoba
1329 Niakwa Road East, Unit 12
Winnipeg, MB R2J 3T4
Telephone: 204-255-9720

Down to Earth Labs
3510 - 6 Avenue North
Lethbridge, AB T1H 5C3
Telephone: 403-328-1133
Fax: 403-320-1033

Exova
Alberta
7217 Roper Road
Edmonton, AB T6B 3J4
Telephone: 780-438-5522
Fax: 780-434-8586
Email: americas@exova.ca

#5 - 2712 - 37 Avenue N.E.
Calgary, AB T1Y 5L3
Telephone: 403-291-2022
Fax: 403-291-2021
Email: americas@exova.com

7407 Twp Rd 485
Drayton Valley, AB T7A 1R8
Telephone: 780-542-6812
Fax: 780-542-4844
Email: americas@exova.com

6203B - 43 Street
Lloydminster, AB T9V 2W9
Telephone: 780-874-9245
Fax: 780-874-9248
Email: americas@exova.com

11301 - 96 Avenue
Grande Prairie, AB T8V 5M3
Telephone: 780-532-8709
Fax: 780-539-0611
Email: americas@exova.com

Farmer's Edge Laboratories
1357 Dugald Rd.
Winnipeg, MB R2J 0H3
Telephone: 204-233-4099
Email: fe.labs@farmersedge.ca

Western Ag Labs
#104 - 110 Research Drive
Innovation Place
Saskatoon, SK S7N 3R3
Telephone: 306-978-1777
Toll-free: 1-877-978-1777
Fax: 306-978-4140
Email: info@westernag.ca

1.2.2 Water Licensing Resources

Alberta
Alberta Environment and Sustainable Resource Development
Toll-free:1-800-222-6514
Website: www.environment.alberta.ca/02206.html

Saskatchewan
Water Security Agency (Head Office)
400 - 111 Fairford St. E.
Moose Jaw, SK S6H 7X9
Telephone: 306-694-3900
Fax: 306-694-3105
Email: comm@wsask.ca

Irrigation Branch (Saskatchewan Ministry of Agriculture)
Room 226, 3085 Albert Street
Regina, SK S4S 0B1
Telephone: 306-787-4660
Fax: 306-787-0428

Manitoba
Manitoba Water Stewardship (Water Licensing Office)
Box 16, 200 Saulteaux Crescent
Winnipeg, MB R3J 3W3
Toll-free: 1-800-214-6497
Telephone: 204-945-3983 (Water Licensing Office)
Email: mws@gov.mb.ca

1.3 Seed Suppliers

All contact information current at time of publication. Please note, list is not comprehensive, nor does it serve as an endorsement of any particular product or company.

Dominion Seed House
PO Box 2500
Georgetown, ON L7G 5L6
Telephone: 905-873-3037
Email: mail@dominion-seed-house.com

Heritage Harvest Seed
P.O. Box 279
Carman, MB R0G 0J0
Telephone: 204-745-6489
Email: seed@heritageharvestseed.com

Johnny's Selected Seeds
PO Box 299
Waterville, ME 04903
Telephone: 207-861-3900
Fax: 207-238-5375
Email: csiladi@johnnyseeds.com

McKenzie Seeds
1000 Parker Blvd.
Brandon, MB R7A 6E1
Toll-free: 1-800-665-6340
Toll-free Fax: 1-888-883-8222
Email: customerservice@mckenzieseeds.com

Salt Spring Seeds
Box 444, Gagnes P.O.
Salt Spring Island, BC V8K 2W1
Telephone: 250-537-5269
Email: dan@saltspringseeds.com

SeedWay
99 Industrial Road
Elizabethtown, PA 17022
Toll-free: 1-800-952-7333
Toll-free Fax: 1-800-645-2574
Email: vegseed@seedway.com

Siegers Seed Co.
13031 Reflections Drive
Holland, MI 49424
Telephone: 616-786-4999
Fax: 616-994-0333

Stokes
PO Box 10
Thorold, ON L2V 5E9
Telephone: 905-688-4300
Email: stokes@stokeseeds.com

T&T Seeds
Box 1710
Winnipeg, MB R3C 3P6
Telephone: 204-895-9962
Fax: 204-895-9967
Email: garden@ttseeds.com

Veseys
PO Box 9000
Charlottetown, PE C1A 8K6
Toll-free: 1-800-363-7333
Fax: 1-800-686-0329
Email: customerservice@veseys.com

West Coast Seeds
3925 64th St., RR 1
Delta, BC V4K 3N2
Toll-free: 1-888-804-8820

William Dam Seeds
279 Hwy 8
Dundas, ON L9H 5E1
Telephone: 905-628-6641
Fax: 905-627-1729
Email: info@damseeds.com

1.4 Equipment

All contact information current at time of publication. Please note, this list is not comprehensive nor does it serve as an endorsement of any particular product or company.

1.4.1 Horticultural Production Suppliers (fertilizer, pesticides, mulch, etc.)

AGRIPACK
RR 8 - 26 - 18
Lethbridge, AB T1J 4P4
Telephone: 403-327-9843
Email: info@broxburn-vegetables.com

American AgroFabric
Telephone: 780-663-7600
Email: info@agrofabric.com

Apache Seeds LTD.
10136 - 149 Street NW
Edmonton, AB T5P 1L1
Telephone: 780-489-4245

Bio-way Inc.
RR 2
Leduc, AB
Telephone: 780-956-1067
Email: vsbretin@hotmail.com

Direct Solutions: a division of Agrium Advanced Technologies
Toll-free: 1-800-661-2991
Website: www.growercentral.com

Early's Farm and Garden Centre
2615 Lorne Avenue
Saskatoon, SK S7J 0S5
Telephone: 306-931-1982
Toll-free: 1-800-667-1159
Fax: 306-931-7110
Website: www.earlysgarden.com/

Growers Supply LTD.
6027 - 64 Street
Taber, AB T1G 2H2
Telephone: 403-223-5380
Fax: 403-223-5381

Growers Supply Company LTD.
2605 Acland Road
Kelowna, BC V1X 7J4
Telephone: 250-765-4500
Fax: 250-765-4545

JVK
1894 - 7th Street
P.O. Box 910
St. Catharines, ON L2R 6Z4
Telephone: 905-641-5599
Fax: 905-684-6260
Email: sales@jvk.net

Ken-Bar
355 Paul Road
PO Box 24966
Rochester, NY 14624-0966
Toll-free: 1-800-336-8882
Fax: 585-295-3608
Email: info@ken-bar.com

PlastiTech
1430, rue Notre-Dame
C.P. 3589
Saint-Remi, QC J0L 2L0
Telephone: 450-454-2230
Fax: 450-454-2789
Email: nseguin@plastitech.com

Professional Gardener Co. LTD.
915 - 23 Avenue SE
Calgary, AB T2G 1P1
Telephone: 403-263-4200

Sturgeon Valley Fertilizers
Box 292
St. Albert, AB T8N 1N3
Telephone: 780-458-6015
Fax: 780-460-7373

TWD Lawn & Garden Products
12340 - 184 Street NW
Edmonton, AB T5V 0A5
Telephone: 780-452-8788

Vanden Bussche Irrigation
Box 304
2515 Pinegrove Road
Delhi, ON N4B 2X1
Toll-free: 1-800-387-7246
Fax: 519-582-1514

Vegetable Growers Supply Company
PO Box 757
1360 Merrill Street
Salinas, CA 93902
Telephone: 831-759-4600
Fax: 831-424-3401

1.4.2 Post-Production Supplies (Picking, Cooling, Packing, etc.)

Alliance Rubber Company
210 Carpenter Dam Road
P.O. Box 20950
Hot Springs, AR 71901
Toll-free: 1-800-626-5940

Atlantic Packaging Products
111 Progress Avenue
Scarborough, ON M1P 2Y9
Telephone: 416-298-8101
Fax: 416-297-2218

Bedford Industries
1659 Rowe Avenue
PO Box 39
Worthington, MN 56187-0039
Toll-free: 1-877-233-3673
Fax: 507-376-6742

British Canadian Importers
102 - 4599 Tillicum Street
Burnaby, BC V5J 3J9
Telephone: 604-681-3554
Fax: 604-681-0567

Canacoast Sales & Marketing LTD.
1878 - 130A Street
Surrey, BC V4A 8R7
Telephone: 604-538-5565

Chantler Packaging Inc.
880 Lakeshore Road East
Mississauga, ON L5E 1E1
Telephone: 905-274-2654
Email: info@chantlerpackaging.com

Coderre Packaging
413 Yamaska Street (Road 122)
St-Germain-de-Grantham
Drummondville, QC J0C 1K0
Telephone: 819-395-4223
Fax: 819-395-2087
Email: coderre@embcoderre.com

Crown Packaging
Lower Concourse, #19 - 2016
Sherwood Drive
Sherwood Park, AB T2C 3B4
Toll-free: 1-888-723-3480
Fax: 780-449-0076

Friesen Plastics Inc.
2926 - 7 Avenue N.
Lethbridge, AB T1H 5C6
Telephone: 403-328-0364
Fax: 403-320-5735
Email: sales@friesenplastics.com

Intercrate Containers Corp
Suite 105 - 657 Marine Drive
West Vancouver, BC V7T 1A4
Telephone: 604-922-4446
Website: www.intercratecontainer.com

Lloyd Bag Co.
114 St. Clair Street
P.O. Box 208
Chatham, ON N7M 5K3
Toll-free: 1-800-549-2247
Fax: 519-352-3413
Email: howard@lloydbag.com

Macro Plastics (Corporate)
2250 Huntington Drive
Fairfield, CA 94533-9732
Toll-free: 707-437-1200
Fax: 707-437-1201
Website: www.macroplastics.com

Pro-Western Plastics LTD.
30 Riel Drive
P.O. Box 261
St. Albert, AB T8N 3Z7
Telephone: 780-459-4491
Toll-free fax: 1-800-428-4756

Rockford Package Supply
10421 Northland Dr.
Rockford, MI 49341
Toll-free: 1-800-444-7225
Fax: 616-866-4921

Second Packaging Inc.
4325 Steeles Ave W.
Downsview, ON M3N 1V7
Telephone: 416-736-7657
Fax: 416-736-4772
Email: secondpackaging@rogers.com

Shippers Supply
18411 - 104 Ave NW
Edmonton, AB T5S 2V8
Telephone: 780-482-1106
Email: inquiry@shipperssupply.com

Super Poly LTD.
9311 - 28 Ave.
Edmonton, AB T6N 1N1
Telephone: 780-462-4712
Fax: 780-462-4721
Email: sales@superpoly.ca

Thunderbird Plastics
6969 Shirley Avenue
Burnaby, BC V5J 4R4
Toll-free: 1-888-77T-BIRD (1-888-778-2473)
Telephone: 604-433-5624
Fax: 604-433-6231
Email: info@thunderbirdplastics.com
Website: www.thunderbirdplastics.com/

Tilton
175 rue des Grands Lacs
Saint-Augustin de Desmaures, QC G3A 2K8
Telephone: 418-878-6100
Fax: 418-878-6145
Email: tiltonplastic@tiltonplastic.com

Unisource
4300 Hickmore Street
St-Laurent, QC H4T 1K2
Email: ebusiness@unisource.ca

Western Canada Enterprises LTD.
Burnaby, B.C.
Telephone: 604-420-1186
Fax: 604-420-8968

Western Concord
14743 - 134 Ave NW.
Edmonton, AB T5L 4S9
Telephone: 780-452-5681
Email: info@westernconcord.com

Wellington Wood Products
410 Sligo Road W. Box 220
Mount Forest, ON N0G 2L0
Telephone: 519-323-1060
Fax: 519-323-3432
Email: wwp@wightman.ca

1.4.3 Equipment Suppliers

BEI Incorporated
1375 Kalamazoo Street
South Haven, MI 49009
Telephone: 269-637-8541
Fax: 269-637-4233
Email: sales@beiintl.com
Website: www.beiinternational.com/

Eckert Machines
3841 Portage Rd
Niagara Falls, ON L2J 2L1
Telephone: 905-356-8356
Fax: 905-356-1704

Korvan Division (OXBO International Corp.)
270 Birch Bay Lynden Road
Lynden, WA 98264
Telephone: 360-354-1500
Fax: 360-354-1300
Website: www.korvan.com

Northern Horticulture Equipment
Box 752
Calmar, AB T0C 0V0
Telephone: 780-987-3217
Fax: 780-987-4364

Oxbo International
Numerous locations throughout the US
Website: www.oxbocorp.com

Prairie Agriculture Machinery Institute
P.O. Box 1150
2215 - 8th Ave
(Highway 5 West)
Humboldt, SK S0K 2A0
Toll-free: 1-800-567-7264
Fax: 306-682-5080
Email: Humboldt@pami.ca

R&W Equipment LTD.
5221 - 11th Line RR#1
Cookstown, ON L0L 1L0
Telephone: 705-458-4003
Fax: 705-458-1480
Email: rwequipment@bellnet.ca

Roeters Farm Equipment
565 East 120 Street
Grant, MI 49327
Telephone: 231-834-7888
Email: roeters.eq@att.net

Slimline Manufacturing
559 Okanagan Ave. E
Penticton, BC V2A 3K4
Toll-free: 1-800-495-6145
Fax: 250-492-7756

Tram Sales
10757 - 182 Street
Edmonton, AB T5S 1J5
Telephone: 780-484-2231
Fax: 780-484-0817
Email: info@tramsales.com

Univerco
713, route 219
Napierville, QC J0J 1L0
Telephone: 450-245-7152
Fax: 450-245-0068
Email: info@univerco.net

Weed Badger
5673 - 95 Avenue SE
Marion, ND 58466-9718
Telephone: 701-778-7511
Fax: 701-778-7501
Email: inquiry@weedbadger.com

Willsie Equipment Sales Inc.
R.R. # 1
9516 Northville Road
Thedford, ON N0M 2N0
Toll-free: 1-800-561-3025

Zeller & Sons Enterprises LTD.
R.R. #1, 2360 Naramata Road
Naramata, BC V0H 1N0
Toll-free: 1-866-496-5338
Email: info@zellerandsons.com

1.5 Bees

Alberta Beekeepers Commission
#102, 11434 - 168 Street
Edmonton, AB T5M 3T9
Telephone: 780-489-6949
Fax: 780-487-8640
Email: gertie.adair@albertabeekeepers.org
Website: www.albertabeekeepers.org

Saskatchewan Beekeepers Association (SBA)
Box 55, RR 3
Yorkton, SK S3N 2X5
Telephone: 306-783-7046
Fax: 306-786-6001
Website: www.saskbeekeepers.com

Manitoba Beekeepers Association
Website: www.manitobabee.org

1.6 Organics

1.6.1 Provincial Associations

Organic Alberta
Unit #1, 10329 - 61 Avenue
Edmonton, AB T6H 1K9
Toll-free: 1-855-521-2400
Website: www.organicalberta.org

Saskatchewan Organic Directorate
PO Box 32066
RPO Victoria Square
Regina, SK S4N 7L2
Telephone: 306-569–1418
Website: www.saskorganic.com

Manitoba Organic Alliance
C/O Hermann Grauer
#5 Life Science Parkway
Steinbach, MB R5G 2G7
Telephone: 204-546-2099

1.6.2 Organic Production

Organic Agriculture Centre of Canada
Dalhousie University
Faculty of Agriculture
P.O. Box 550
Truro, NS B2N 5E3
Telephone: 902-893-7256
Fax: 902-896-7095
E-mail: andrew.hammermeister@dal.ca
Website: www.organicagcentre.ca

Additional Information on Organic Production
Alberta
Website: www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/bdv11369

Saskatchewan
Website: www.agriculture.gov.sk.ca/Crop-Organics

1.7 Food Processing

1.7.1 Food Processing/Development Centres

Alberta
Food Processing Development Centre
6309 - 45 Street
Leduc, AB T9E 7C5
Telephone: 780-986-4793
Fax: 780-986-5138

Saskatchewan
Food Centre
117 - 105 North Road
Saskatoon, SK S7N 4L5
Telephone: 306-933-7555
Fax: 306-933-7208
E-mail: info@foodcentre.sk.ca
Website: www.foodcentre.sk.ca

Manitoba
Food Development Centre
Box 1240
810 Philips Street
Portage la Prairie, MB R1N 3J9
Toll-free: 1-800-870-1044
Telephone: 204-239-3150
Fax: 204-239-3180

1.7.2 Food Processor Associations

Alberta Food Processors Association
Suite 100W 4760 - 72 Ave SE
Calgary, AB T2C 3Z2
Telephone: 403-201-3657
Fax: 403-201-2513
E-mail: info@afpa.com
Website: www.afpa.com

Saskatchewan Food Processors Association
8B - 3110 - 8th Street East #389
Saskatoon, SK S7H 0W2
Toll-free: 1-866-374-7372
Telephone: 306-683-2410
Fax: 306-683-2420
E-mail: schneider@sfpa.sk.ca
Website: www.sfpa.sk.ca/

Manitoba Food Processors Association
Unit 12 - 59 Scurfield Boulevard
Winnipeg, MB T3Y 1V2
Telephone: 204-982-MFPA (6372)
Fax: 204-632-5143
E-mail: mfpa@mfpa.mb.ca
Website: www.mfpa.mb.ca

1.8 Food Safety

Canada GAP
245 Stafford Road West, Suite 312
Ottawa, ON K2H 9E8
Telephone: 613-829-4711
Fax: 612-829-9379
Website: www.canadagap.ca

1.9 Marketing Information

1.9.1 Exporting Resources

Foreign Affairs and International Trade Canada
TCS Enquiries Service (BCI)
125 Sussex Drive
Ottawa ON K1A 0G2
Toll-free: 1-888-306-9991
Fax: 613-996-9709
E-mail: enqserv@international.gc.ca
Website: www.infoexport.gc.ca/ie-en/EmbassyCountryListing.jsp?rid=12

Agri-Food Trade Service
Public Information Request Services
Agriculture and Agri-Food Canada
Sir John Carling Building
930 Carling Ave
Ottawa, ON K1A 0C7
Telephone: 613-773-1000
Fax: 613-773-1081
E-mail: info@agr.gc.ca
Website: www.ats-sea.agr.gc.ca/intro/index-eng.htm

Saskatchewan Trade and Export Partnership (STEP)
P.O. Box 1787
320 - 1801 Hamilton St.
Regina, SK S4P 3C6
Telephone: 306-787-9210
Fax: 306-787-6666
Email: inquire@sasktrade.sk.ca
Website: www.sasktrade.sk.ca

STEP (continued)
500 - 402 21st Street E.
Saskatoon, SK S7K 0C3
Telephone: 306-933-6551
Fax: 306-933-6556
Email: inquire@sasktrade.sk.ca
Website: www.sasktrade.sk.ca

1.9.2 Foreign Labour

Hiring Agricultural Foreign Workers in Canada
Website: www.esdc.gc.ca/eng/jobs/foreign_workers/agriculture/index.shtml

2.0 Building Resources

Canada Plan Service
Website: www.cps.gov.on.ca

3.0 Publications

Alberta Agriculture and Rural Development
Website: www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/ipc4687

Manitoba Agriculture, Food and Rural Development
Website: www.gov.mb.ca/agriculture/crops/guides-and-publications

4.0 Feel method for estimating soil water available for crop use

Soils can vary greatly in texture from being very fine (clay) to very coarse (sand) within a crop root zone. Because soil texture can change quite quickly, so can the amount of water the soil is able to hold.

Texture	Available moisture
Loamy sand	8 - 12 mm/0.1 m (0.9 - 1.4 in./ft.)
Sand loam	10 - 15 mm/0.I m (1.2 - 1.8 in./ft.)
Loam	14 - 18 mm/0.I m (1.7 - 2.1 in./ft.)
Sand clay loam, clay loam, clay	15 - 20 mm/0.1 m (1.8 - 2.4 in./ft.)
Silty clay loam, silt loam	16 - 22 mm/0.I m (1.9 - 2.6 in./ft.)

It is important to know and to be able to calculate the amount of water in the soil root zone in order to understand the amount of water available for crop use.

The allowable depletion level is the amount of soil water that can safely be removed from the root zone by a crop before irrigation is required. For most crops, the allowable depletion level has been determined to be 50 per cent.

The simplest way to determine soil water content is by the "feel" method. By feeling, squeezing and observing a handful of soil, the amount of water in the soil can determined. The following chart outlines the various characteristics of soil based on different contents of water.

		Feel or appearance of soils*		
	Per cent of available water remaining	**Moderately course texture**	**Medium texture**	**Moderately fine texture**
Do not irrigate	At field capacity 100	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.	Same as sandy-loam.	Same as sandy-loam.
	75 to field capacity	Forms a weak ball, breaks easily, will not slide.	Forms a ball and is very pliable, slicks readily if relatively high in clay.	Easily ribbons out between fingers, has a slick feeling.
Irrigate special crops	50 to 75	Tends to ball under pressure, but seldom will hold together.	Forms a ball, somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, will ribbon out between thumb and forefinger.
Irrigate	25 to 50	Still appears to be dry, will not form ball with pressure.	Somewhat crumbly, but will hold together from pressure.	Somewhat pliable, will ball under pressure
	0 to 25	Dry, loose, single grained, flows through fingers.	Powdery, dry, sometimes slightly crusted, but easily breaks down into powdery condition.	Hard, baked, cracked and sometimes has loose crumbs on surface.

* Ball is formed by squeezing a handful of soil firmly.

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