

Guide to Commercial Potato Production on the Canadian Prairies



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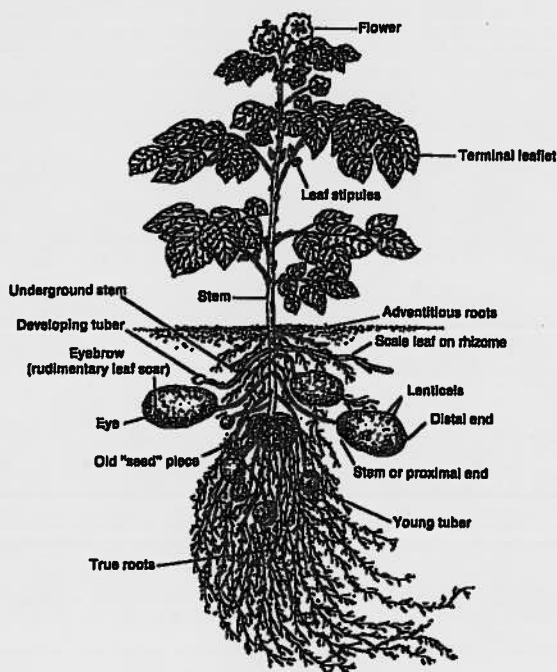
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1 Botany of the Potato Plant

1.1 The Potato Plant and Tubers

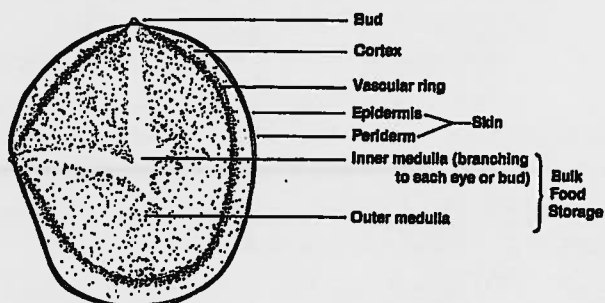
The potato tuber is an enlarged portion of an underground stem or stolon (Figure 1.1-1). Tuber eyes are the buds from which next season's growth will emerge. Eyes are concentrated near the apical end of the tuber, with fewer near the stolon or basal end. Eye number and distribution are characteristic of the variety.

Figure 1.1-1 Diagram of a potato plant. For simplicity, one main stem is shown. Productive plants may have two or more main stems. (Courtesy of Alberta, Food and Rural Development)



The tuber skin is composed of two layers of cells: an outer layer of single cells called the epidermis, underlain by several layers of corky cells called the periderm (Figure 1.1-2). The cells in the periderm layer may contain a pigment that produces coloured potatoes. Below the periderm is the cortex, followed by the vascular ring, which contains the cells that transport food products to the tuber from the above ground stems. Internal to the vascular ring is the medulla. The medulla represents the primary storage area for the potato tuber. Excess food produced by the potato plant is transported to the medulla via the vascular tissue. Cells in the medulla increase in number and size as they are supplied with food, causing the tuber to increase in size.

Figure 1.1-2 Cross-section of a potato tuber (Courtesy of Alberta Agriculture, Food and Rural Development)



1.2 Potato Plant Growth

Growth and quality of potatoes are influenced by environmental factors such as temperature, moisture, light, soil type and nutrients. Many factors that influence potato growth are largely uncontrollable: length of growing season, air and soil temperatures, light intensity and duration, humidity and wind. Other factors that influence growth of the crop can be controlled by the grower: variety of potato, size of mother seed tubers, seed-piece cutting, seed-piece types, cut-seed size, planter operation, plant stand, stem population, moisture, nutrition, pest management, planting date and harvest date. Only when all factors are at optimum levels can the most profitable yields of quality potatoes be attained.

Temperature and length of growing season

The potato is a cool-season crop that grows well in certain areas of the Prairie Provinces. The rate of development of sprouts from seed pieces depends on soil temperature. Very little sprout elongation occurs at 43°F (6°C), elongation is slow at 48°F (9°C) and is maximized at about 64°F (18°C). The optimum soil temperature for initiating tubers is 61-66°F (16-19°C). Tuber development declines as soil temperatures rise above 68°F (20°C) and tuber growth practically stops at soil temperatures above 86°F (30°C). The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favour development of large tubers.

Yields are highest when average daytime temperatures are about 69°F (21°C). Cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances storage of starch in the tubers.

From the temperature information in the above paragraphs Physiological Days (P-Days) can be calculated. P-Days are a measure of the heat useful for the growth and development of potatoes. In the potato production areas of the Prairies, the highest average accumulation of P-Days, 850-950, occurs south of Lake Manitoba to the U.S. border and the lowest accumulation, 750-900, occurs in the seed production areas south of Edmonton and in Central Saskatchewan (Plate 1).

The varieties currently grown on the Prairies require anywhere from 800-1000 P-Days to reach full maturity. An early-maturing variety such as Norland requires 800 P-Days, and later maturing varieties such as Russet Burbank require 1000 P-Days. Growing a potato variety in an area with insufficient P-Days will reduce yield and affect tuber quality factors such as accumulation of solids and fry colour (See 1.5 *Tuber Quality*). The average accumulation of P-Days is insufficient in many parts of the Prairies to produce late season varieties where the crop must be fully mature before harvest. These areas may be suitable for seed or table production, where the crop is killed or harvested before full maturity.

Moisture

Potatoes require a continuous supply of soil water along with adequate soil aeration. Yields are greatest when soil moisture is maintained above 65% of the available soil water (ASW) capacity

Tuber set is particularly sensitive to moisture stress. There are generally fewer tubers set when available soil moisture is maintained below 65% of the available soil water (ASW) capacity. The amount of water needed by potatoes varies with the soil type, temperature, humidity, air movement, plant and stem populations, variety and cultural practices. In Alberta and Saskatchewan, too little moisture and fluctuating moisture levels are more common than excessive moisture. In Manitoba, the situation is reversed. Too much moisture generally causes more problems than too little moisture. Low or fluctuating moisture levels can contribute to common scab, early dying, hollow heart, knobby tubers, low dry matter, low tuber set, and low yield. Excessive soil moisture resulting in poor aeration and water logging of the soil reduces yields and in extreme cases causes tuber rot. An excess of moisture may also lead to enlarged lenticels, which are openings of the epidermis. This detracts from their appearance and allows entry of disease organisms, causing tuber rot in storage.

1.3 Growth Stages

The development of potatoes can be broken down into five distinct growth stages (Figure 1.3-1).

Growth Stage I: Sprout Development

This stage begins with sprouts developing from the eyes and ends at emergence from the soil. The seed piece is the sole energy source for growth during this stage.

Growth Stage II: Vegetative Growth

This stage, in which all vegetative parts of the plants (leaves, branches, roots and stolons) are formed, begins at emergence and lasts until tubers start to develop. Growth stages I and II last from 30 to 70 days depending on planting date, soil temperature and other environmental factors, the physiological age of the tubers, and the characteristics of particular cultivars.

Growth Stage III: Tuber Set/Initiation

Tubers are forming at salong tips, but are not yet enlarging. This stage will last approximately 2 weeks.

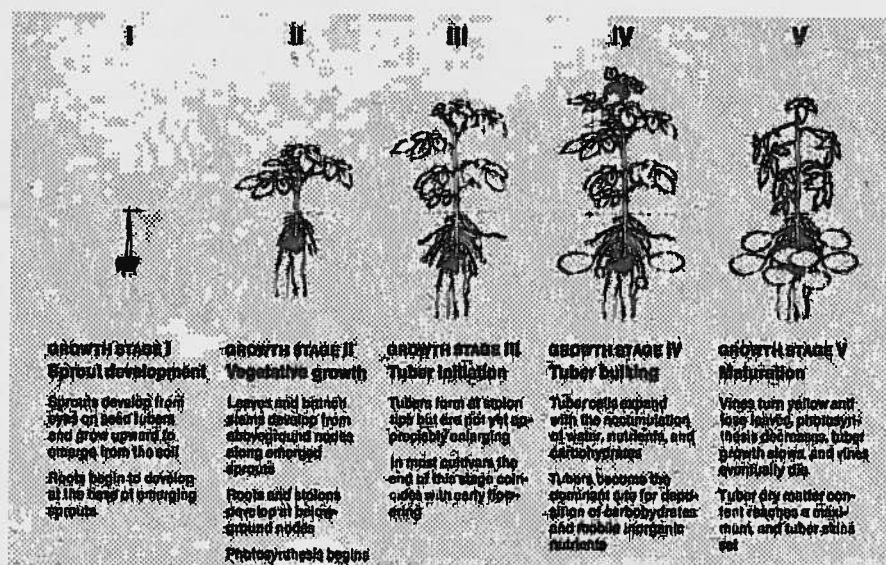
Growth Stage IV: Tuber Bulking

Tuber cells expand with the accumulation of water, nutrients and carbohydrates. Tuber bulking is the growth stage of longest duration. Depending on date of planting and cultivar, bulking can last up to three months.

Growth Stage V: Maturation

Vines turn yellow and lose leaves, photosynthesis gradually decreases, tuber growth rate slows and the vines die. This stage may not occur when growing a long season variety like Russet Burbank in a production area with a short growing season.

Figure 1.3-1 Growth stages of the potato. (Courtesy of the American Phytopathological Society)



1.4 Tuber Initiation and Growth

Growth Stage III (Figure 1.3-1) tuber initiation or tuberization starts when the ends of stolons begin to swell. This occurs between early and late June depending on location, planting date, climate, soil type, and variety. Tubers form when the plant produces more carbohydrates than are required for vine growth. Varying weather and moisture conditions cause uneven tuber set and growth.

The number of tubers formed per plant is called the tuber set. The plant may initially produce 20 to 30 small tubers, but only 5 to 15 tubers typically reach maturity. The growing plant absorbs some of the tubers in the original set. The number of tubers that achieve maturity is related to available moisture and nutrition. Optimum moisture and nutrient levels early in the growing season are critical to the maintenance and development of tubers. Maintaining available soil moisture above 65% of the available soil water (ASW) capacity has been shown to produce high tuber set when compared to lower moisture levels.

Uneven growth of the potato plant, and therefore uneven growth of tubers, can result in abnormalities in tuber shape. Fluctuating temperatures, moisture, and nitrogen, especially in the formative stage, can cause malformed tubers. Uneven growth caused by variable climactic conditions is worsened by poor plant stand and variability between plants caused by variable seed-piece types, sizes and spacings.

1.5 Tuber Quality (M. Scanlon)

Nutritional Quality

Potatoes are a nonfattening, nutritious and wholesome food that supplies many important nutrients to the diet. Potatoes contain approximately 78% water, 22% dry matter (specific gravity) and less than 1% fat. About 82% of dry matter is carbohydrate, mainly starch, with some dietary fibre and small amounts of various simple sugars.

**Potatoes are a
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Although potatoes contain only relatively little protein (0.6-1.2% of the fresh weight), their nutritional quality is better than cereals or soybeans. Potatoes contain at least 12 essential vitamins and minerals, are a source of vitamin C, thiamine, iron and folic acid.

Fresh-Market

Quality influences consumer preference and product saleability. Good quality potatoes are clean, uniform in shape and size, have an unmarked skin and firm flesh, are free of internal defects, and have shallow eyes. Consumers do not like the waste of trimming potatoes with deep eyes and surface defects. Other tuber defects that may adversely influence quality are greening, secondary growth, growth cracks, scab, storage rots, internal black spot, skinning, *Rhizoctonia* sp. sclerotia, bruising and skinning or other mechanical damage.

In addition to physical quality and appearance, fresh market potatoes must also have good cooking and eating quality. The main cooking quality factors for home-prepared potatoes are texture, colour, flavour and odour. The texture of a cooked potato is directly related to dry matter content. Potatoes are described as mealy and dry if they have a high dry matter content, or moist to wet with a low dry matter. Potatoes such as Russet Burbank, which have a high dry matter content, have a dry, mealy texture when baked, but when boiled they may slough or break up. Potatoes, such as Norland, with a lower specific gravity are inclined to be undesirably wet when baked, but hold together well when boiled.

White-fleshed potatoes are expected to have a creamy white colour when boiled or baked. Yellow-fleshed varieties should retain their characteristic yellow colour during cooking. White or yellow-fleshed potatoes should exhibit minimal after-cooking darkening. This darkening, which is often more prevalent at the stem end of the tuber, is caused by an accumulation of a dark pigment created by the reaction between chlorogenic acid and iron, both naturally occurring compounds in potatoes. Varieties such as Norland, which naturally contain higher amounts of chlorogenic acid, darken more than varieties containing less chlorogenic acid. In the home, after-cooking darkening may be controlled with lemon juice or vinegar (which contain acid). In the commercial potato processing industry sodium acid pyrophosphate is used to reduce darkening after cooking.

Cooked potatoes are expected to have "normal" potato flavour and aroma, without off-flavours or odours. Glycoalkaloids, such as solanine and chaconine, which are present at low levels (2-15 mg/100 g fresh tuber weight) in all potatoes, represent important flavour components. Collectively, this class of compounds is referred to as total glycoalkaloids (TGA). If TGA levels are between 10 and 20 mg/100 g fresh weight the potatoes are bitter when eaten and are potentially toxic if levels are greater than 20 mg/100 g. Twenty (20)mg TGA/100g fresh weight is the maximum allowed by Health Canada.

Surface greening of the tubers often signals the development of bitterness due to TGA accumulation, although the development of the bitter alkaloid compounds and green colour are independent. When potatoes are exposed to light, the green pigment chlorophyll forms, and independent chemical reactions in the outer layer of the potato tuber are triggered, increasing TGA levels. Moderately green tubers should not be consumed without first taste testing the peel of several raw tubers. Bitterness or a burning sensation indicates that TGA levels are too high and the potatoes

should be discarded. Elevated TGA levels in potatoes may result not only from exposure to light but also from harvesting immature potatoes, bruising, skinning, improper storage temperature control, wet conditions prior to harvest, chilling or freezing. Potatoes harvested cold should be slowly warmed to 40-50°F (10-15°C) for 14 days after harvest before the temperature is reduced for long-term storage. Unlike other problems associated with potato quality such as after-cooking darkening, TGA accumulation cannot be counteracted with chemicals or special processing techniques. Not all glycoalkaloids leach from potatoes into blanching or cooking water, and they are not destroyed at the high temperatures associated with boiling, baking or deep-frying.

French Fry Quality

Four primary factors determine French fry quality: dry matter, levels of reducing sugars, defects and flavour. One of the most important qualities of French fry potatoes is high dry matter, which is measured as specific gravity or percent solids. As the specific gravity increases, the water content of the potato decreases. French fry processing removes water from the potato, hence the higher the water content of the potato, the more water or weight lost during processing resulting in a lower yield of fries. Potatoes with a high specific gravity produce a greater yield of fries than potatoes with low specific gravity. Specific gravity also has a direct bearing on the amount of oil absorbed by the potato slices during the deep frying process. Fries made from tubers with low specific gravity absorb more oil than fries from tubers with high specific gravity. Although some oil absorption during deepfrying is desirable for flavour development, too much results in limp, greasy fries. Low specific gravities increase production costs because more oil is used in the frying process.

One of the most important qualities of French fry potatoes is high dry matter.

French fries should have a uniform light cream to golden colour. French fry colour is largely determined by the reducing sugar content of the potato tuber: potatoes with high reducing sugar levels make dark fries. When potatoes are fried, the reducing sugars react with amino acids in the tuber to form dark products in a nonenzymatic browning reaction. The concentration reducing sugars in the tubers depends on variety, growing conditions, maturity, and storage conditions. The processor can make some adjustments to fry colour during processing, primarily by manipulating blanching

conditions. Plate #2 shows the range of fry colours that occur. Processors prefer the lightest fry colour shown in Plate 2. Defects such as sunburn, net necrosis, sugar ends, bruises, carbon spots and light and dark brown areas, negatively influence the appearance of the finished French fry and reduce its value on the market.

High quality French fries have a good potato flavour, are free from rancidity, bitterness, or offodours. Their external surfaces should be moderately crisp showing no separation from the inner portion. The inside is tender, mealy and free from sogginess. The contrast in texture between inner and outer portions contributes to the pleasurable textural sensation when the fries are chewed. Some fries have a coating applied (e.g., starch paste based coatings) to enhance this textural contrast.

Potato Chip Quality

Good quality potato chips have a light colour with little vascular discolouration. As with French fries, the colour of potato chips depends on the reducing sugar content of the potatoes. However, potato chip processors have slightly less control over reducing sugar levels because blanching is not an option in the chipping process. High specific gravity is particularly important in the production of potato chips because of greater surface area to volume ratio in chips compared to fries. Chip crispness and lack of oiliness increases with increasing specific gravity.

Potato chips must have a pleasing and desirable flavour, thus potatoes used in chipping must not be bitter or have other off-flavours. The flavour of potato chips is more complex than that of boiled, baked or mashed potatoes, since the cooking temperatures are higher, and the absorbed oil contributes to the overall flavour profile of the product.

2 Potato Marketing and Cost of Productions

2.1 Marketing

Manitoba (L. MacIntosh)

The marketing of all potatoes produced in Manitoba is regulated under The Manitoba Vegetable Producers' Marketing Plan, Regulation #247/87. This regulation authorizes Peak of the Market to pass certain orders and regulations controlling the marketing of potatoes produced in the province of Manitoba. Potatoes grown under a preplant contract with a specific processor for processing crop processing on their premises are exempt from these regulations and orders. However, marketing in excess of the contracted volumes for processing (surplus) does fall under the regulations and orders of Peak of the Market. At the present time, Peak of the Market has entered into an agreement giving the processing associations (Keystone Vegetable Growers Association and the Chipping Growers Association of Manitoba) the authority to act as Peak of the Market's agent to sell surplus potatoes destined for the processing market only.

Peak of the Market is a non-profit corporation under the direction of nine members elected by registered producers. Five members are potato producers, one is a member at large and three are root crop producers. Peak of the Market operates as a central selling desk, with growers delivering produce based on a quota and delivery system. Peak of the Market also sells nonquota and surplus quota potatoes on a direct price basis to markets outside the quota market area.

Peak of the Market also regulates the packaging of potatoes, with packaging being carried out by Peak of the Market and Stella Produce (1981) Ltd. For further information regarding potato marketing regulations contact Peak of the Market at (204) 632-PEAK (7325).

Saskatchewan (D. Moebis)

Marketing of all potatoes grown in Saskatchewan is the responsibility of the individual grower. There is no single-desk selling agency for Saskatchewan produce. Some producers use the services of a potato broker, while others rely upon personal contacts developed during the course of business. At one time, contracts for potato production were rare, however, in recent years, more producers are relying on short-term (one or two year) contracts to aid in production planning.

The Saskatchewan Seed Potato Growers Association, Inc. (SSPGA) assists in promoting the sale of its members' seed potatoes to national and international

markets. SSPGA publishes an annual Seed Directory and maintains a website (www3.sk.sympatico.ca/sspga) which lists member seed growers and the products they produce. Prospective growers should contact the office of the SSPGA at 306-931-7892 for marketing information, advice and contacts.

Commercial potato growers market a large portion of their production through roadside stands, farmers' markets or packing sheds. Companies such as Riverside Gardens, Martin's Vegetable Produce Ltd., and Pak-Wel Produce (Sask.) Ltd. purchase potatoes for prepacking into various sizes of poly bags and cartons.

Alberta (V. Warkentin)

There is no central potato-marketing agency in Alberta. Producers have the responsibility to market their own crops.

All potatoes grown for processors, whether French fries, chips or other processed products, are grown under contract to the processor. Contracts stipulate variety, number of acres and yield. There is a base price with incentives or disincentives for quality, colour and specific gravity etc. Prices for in-storage potatoes increase every two weeks after November 1. A negotiating committee made up of growers negotiates with processors for all growers and all growers voluntarily accept the negotiated contracts.

Potatoes grown for the fresh market are sold on the open market potatoes or under contract. Open market allows growers to attempt to manage price by marketing when prices are stronger. The fresh market provides an outlet for surplus seed potatoes. In the past, the Potato Growers of Alberta (PGA) has done some promotion of potatoes directly to the consumer.

For specific customers, seed potatoes are grown under contract. Variety and price are established up front. Seed potatoes are also grown as open potatoes and marketed by brokers or dealers. Varieties are selected based on demand or market trends. Brokers/dealers often advise which varieties will have a market. The Alberta Seed Potato Growers Association establishes suggested prices for each generation of seed in November of each year. Individuals can negotiate around the suggested price. ASPGA/PGA promote seed potatoes by media advertising, trade shows and conferences.

2.2 Guidelines For Estimating Potato Cost of Production

The Western Potato Council is planning to develop a budget template that will allow producers to calculate their own cost of production. Until then, assistance and information in preparing a budget can be obtained through your provincial department of agriculture, producer association or the following websites:

- <http://www.agr.gov.sk.ca> Follow the links to crops and horticulture.
- Irrigated Processing Potatoes Cost of Production – Manitoba Agriculture and Food.
<http://www.gov.mb.ca/agriculture/financial/farm/cac30s01.html>.

3 Commercial Potato Production Management

3.1 Varieties (D. Lynch, A. Sullivan, R. Curle)

3.1.1 Variety Selection

Processing

Processors contract specific varieties for French fry and chip production. Russet Burbank, Shepody and Ranger Russet are the major varieties used by French fry companies in Prairie Canada. Shepody and Ranger Russet are used for early, direct (out-of-field) production, while Russet Burbank and Shepody are used for processing out-of-storage. Atlantic, Conestoga (Manitoba only), Snowden, Niska and NorValley are the major varieties used for chip production in Prairie Canada. Atlantic and Conestoga are used for early to midseason direct processing, while Snowden, Niska and NorValley are suited for long-term storage. The Frito Lay Company contracts proprietary chip varieties developed by the Company's breeding program located in Wisconsin. New varieties are routinely evaluated by the processing industry.

Fresh Market

Varieties with red or russet skin, as well as varieties with yellow flesh, make up the major acreage of fresh market varieties in Prairie Canada. Consumer/packer/wholesaler demand determines the varieties grown. Norland, Sangre and Red Pontiac are the major red-skinned varieties; Russet Norkotah is the major russet-skinned variety and Yukon Gold and Bintje are the major yellow-fleshed varieties. New varieties are constantly being evaluated.

Seed Production

The demand for seed potatoes of a specific variety is directly related to the needs of the commercial potato industry in North America. Seed growers should base production on these established markets.

3.1.2 Protected Varieties

Plant Breeders' Rights legislation was enacted in Canada in 1990 and the Plant Variety Protection Act in the USA was amended to include potatoes in 1994. This legislation provides the opportunity for public and private breeders to control production of a variety and collect royalties on the sale of seed. In the future, most new varieties will be protected under this legislation.

3.1.3 Registration of Varieties

All varieties produced in Canada must be registered with the Variety Registration Office of the Canadian Food Inspection Agency and be represented by a Canadian agent. Russet Burbank, Red Pontiac and Bintje do not have a Canadian agent since these varieties were registered prior to the introduction of the requirement. The Variety Registration Committee of the Western Potato Council facilitates registration for Western Canada.

3.1.4 Variety Descriptions

Table 3.1-1 includes descriptions of the leading varieties grown across the Prairie Provinces. Figure 3.1-1 shows the shapes used to describe potato varieties.

Figure 3.1-1 Shapes used to describe potato varieties (Courtesy of Agriculture and Agri-Food Canada)

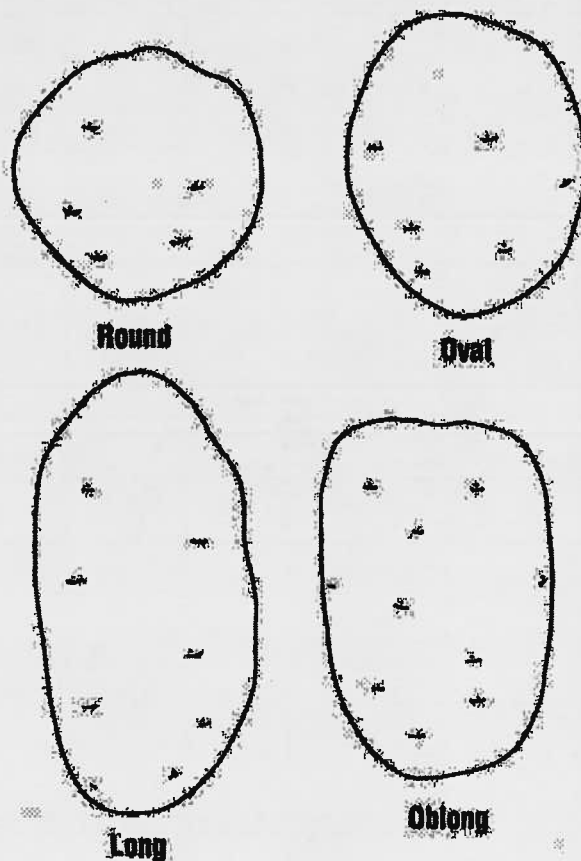


Table 3.1-1 Variety descriptions

Variety	Representative in Canada	Primary Use	Secondary Use	Maturity	Tuber				Characteristics	
					Shape	Eyes	Skin	Flesh	Yield Potential	Specific Gravity
Russet Burbank	None	French fry	Table market (baking)	Late	Long	Moderately shallow	Brown, strongly russeted	White	High	High
Shepody	Agriculture and Agri-Food Canada Potato Research Centre, NB	French fry		Mid-season	Long	Shallow	Smooth, buff	White	Medium-high	Medium
Ranger Russet (Amisk)	Agriculture and Agri-Food Canada Research Centre, Lethbridge, AB	French fry	Table market, count pack	Late	Long	Moderately shallow	Brown, strongly russeted	White	High	High
Atlantic	Agriculture and Agri-Food Canada Research Centre, Lethbridge, AB	Chipping	Early table market	Mid-season	Oval	Moderately shallow	Buff, rough (flaky)	White	High	High
Snowden	Potatoes New Brunswick, Grand Falls, NB	Chipping		Late	Round-oval	Moderately deep	Buff	White	High	High
Niska	Agriculture and Agri-Food Canada Research Centre, Lethbridge, AB	Chipping	Table market	Mid-season	Oval	Moderately deep	Buff	White	High	High
Conestoga	University of Guelph, Guelph, ON	Chipping		Early	Oval-oblong	Shallow, occasionally pink	White, rough (flaky)	White	High	Medium
NorValley	Alberta Seed Potatoes Inc., Taber, AB	Chipping	Table market	Mid-season	Round-oval	Moderately shallow	White	White	High	Medium

Characteristics			Disease		Agronomic Management
Quality	Tuber Defects	Storability	Resistance	Susceptibility	
Excellent French fry and baking quality, moderately resistant to after cooking discoloration.	Susceptible to second growth and hollow heart.	Good, medium to long dormancy.	Common scab, black leg and Fusarium dry rot.	Verticillium wilt, early and late blight, PVY.	Responds to high levels of nitrogen, particularly in terms of the yield of tubers >10 oz (280 g).
Excellent French fry quality.	Resistant to second growth and hollow heart.	French fry quality out of long term storage is variable.	Moderately to Rhizoctonia, Fusarium dry rot and net necrosis.	Common scab, Verticillium wilt, late blight, PVY (symptomless expression) PLRV, and greening due to high position in the hill.	Under certain conditions, post-emergent applications of metribuzin may cause crop injury. Responds to high levels of nitrogen, particularly in terms of the >10 oz (280 g) tuber yield fraction.
Excellent French fry and baking quality.	Resistant to second growth and hollow heart, susceptible to blackspot bruise.	Good potential, but specific gravity must be managed to minimize blackspot bruise.	Moderately to Verticillium wilt, PVX, PVY, and Fusarium dry rot.	Highly susceptible to tuber late blight infection, moderately to common scab.	The Amlak clone produces higher >10 oz (280 g) yield, is more resistant to tuber necrosis associated with infection by <i>Verticillium</i> wilt and is less susceptible to second growth.
Excellent chip quality.	Susceptible to hollow heart and heat necrosis.	Not recommended for storage, susceptible to pressure bruise.	Highly resistant to PVX and tuber net necrosis, moderately to common scab, Verticillium wilt and wart. Highly resistant to race 0 of the golden nematode.		Closer spacing reduces incidence of hollow heart.
Excellent chip quality.	Moderately resistant to second growth and hollow heart, moderately susceptible to bruising.	Excellent, short dormancy.	Moderately to common scab.		
Excellent chip quality.	Moderately resistant to second growth and hollow heart.	Excellent capacity for maintaining fry colour in long-term storage, skin set prior to harvest essential to prevent storage losses due to Fusarium dry rot.	Common scab, moderately resistant to PLRV and early blight.	PVY (symptomless expression), Fusarium dry rot and late blight.	Low set, close row spacing reduces tuber size.
Excellent chip quality.	Moderately resistant to second growth and hollow heart.		Moderately to common scab, early blight, PLRV and net necrosis.	PVY	In the early season, glycoalkaloid values may be unacceptably high. Measure glycoalkaloid levels prior to early harvests.
Excellent chip quality.	Moderately susceptible to second growth, resistant to hollow heart.	Excellent capacity for maintaining fry colour in long-term storage.	Moderately to common scab, early blight and Verticillium wilt.		Low set and close row spacing reduces tuber size.

Variety	Representative in Canada	Primary Use	Secondary Use	Maturity	Tuber				Characteristics	
					Shape	Eyes	Skin	Flesh	Yield Potential	Specific Gravity
Nerland	Cereal Research Centre, Winnipeg, MB	Table market		Early	Oval-oblong	Moderately shallow	Red, smooth	White	High	Medium-low
Sangre	Agriculture and Agri-Food Canada Research Centre, Lethbridge, AB	Table market		Mid-late season	Oval-oblong	Moderately shallow	Red, rough (scaly)	White	High	Medium-high
Red Pontiac	None	Table market		Late	Oval-oblong	Deep	Red, smooth	White	High, drought-tolerant	Medium-low
Russet Norcotah	Agriculture and Agri-Food Canada Research Centre, Lethbridge, AB	Table market		Early-mid season	Oblong-long	Very shallow	Brown, russet	White	High	Medium
Yukon Gold	University of Guelph, Guelph, ON	Table market		Mid-season	Oval	Shallow, pink	Light yellow, smooth	Light yellow	Medium	Medium
Binje	None	Table market		Late	Oblong	Shallow	Light yellow, smooth	Light yellow	High	Medium

Characteristics			Disease		Agronomic Management
Quality	Tuber Defects	Storability	Resistance	Susceptibility	
Excellent boiling quality, wet texture, moderately resistant to sloughing and moderately susceptible to after-cooking darkening.	Moderately susceptible to second growth, moderately resistant to hollow heart.	Poor retention of red skin colour in storage, short dormancy.	Wart, moderately to common scab, Verticillium wilt, PVY and PLRV.	Highly susceptible to silver scurf.	Under certain conditions, post-emergent applications of metribuzin may cause crop injury.
Excellent boiling quality, moderately mealy texture, resistant to sloughing and after-cooking darkening.	Moderately susceptible to second growth and moderately resistant to hollow heart.	Good retention of red skin colour in storage.	Net necrosis, moderately to Rhizoctonia and silver scurf.	Early and late blight, Verticillium wilt, moderately to bacterial soft rot and Fusarium dry rot.	Under certain conditions, post-emergent applications of metribuzin may cause crop injury.
Good boiling and baking quality, wet texture, resistant to after-cooking darkening.	Susceptible to second growth, particularly on oversize tubers, blackspot bruise and shatter bruise.	Good storage potential, medium dormancy.	Moderately to blackleg and net necrosis.	Common scab, Fusarium dry rot, late blight (foliage and tubers), Verticillium wilt, PLRV and PVY.	Under certain conditions, post-emergent applications of metribuzin may cause crop injury. Close row spacing is recommended to limit oversize tubers.
Moderately mealy texture, moderately susceptible to after-cooking darkening.	Very attractive tubers with low defect levels.	Stores well, medium dormancy.	Common scab and silver scurf.	early and late blight, PLRV, and PVY (symptomless expression). Late maturing clonal	
Moderately mealy texture, resistant to after-cooking darkening.	Very attractive tubers with low defect levels, hollow heart occurs in larger tubers.	Excellent with long dormancy.	Moderately to PLRV and net necrosis.	Common scab, early blight, late blight, Rhizoctonia and PVY.	Poor eye distribution can result in blind basal seed pieces. Tuber set is low, close in-row spacing is recommended.
Excellent for boiling, baking and French fries; resistant to after-cooking darkening.	Attractive tubers with low defect levels.	Fair, medium dormancy.	Moderately to PLRV.	Common scab, Fusarium dry rot, wart and PVY.	High tuber set can be managed by increasing in-row spacing.

3.2 Seed Selection, Storage, and Cutting (L. Delanoy, C. Schaupmeyer, D. Ziprick, D. Kirkham)

3.2.1 Seed Selection and Purchase

No amount of cultural management will make up for a seed lot with poor vigour. It is important to select seed that is:

- Certified
- Free from seed-borne diseases
- From a grower with a good reputation
- Free from decay
- Firm (stored properly)
- Physiologically young (produced without major stresses)
- Small in size - 8 oz (225 g) or less
- Uniform in size

No amount of cultural management will make up for a seed lot with poor vigour.

These factors contribute to the production of a complete stand of uniform plants with the potential for high yields of top quality tubers.

Selecting seed that is classified by the Canadian Food Inspection Agency (CFIA) as Certified or better will ensure that the seed meets minimum standards for disease, trueness to variety, physical soundness and tuber size. See *Seed Potato Production Pyramid* in section 6.1 *Seed Potato Act and Regulations* for more details regarding seed classes. In Alberta, provincial legislation specifies that only certified seed potatoes are permitted for planting, unless formal permission is granted by the Potato Growers of Alberta. In Saskatchewan, the Bacterial Ring Rot Control Regulations, included under the Pest Control Act, indicates that a potato grower must plant seed that is certified as foundation or higher class. This also applies to market gardeners. In Manitoba, non-certified seed may be planted, however, much of the potato production is grown under contract for processing and the contract stipulates that the seed must be certified as Elite 4 or higher class.

Insist on receiving a copy of the post harvest test results before agreeing to purchase seed. Viral diseases do not produce visible symptoms on the outer surface of the tubers, so visual appearance is not necessarily a complete indication of quality seed. The incidence of viruses in a certified seed lot can be determined from the post harvest test results issued by CFIA accredited laboratories or CFIA reports of winter nursery tests. See section 6.4 *Post Harvest Testing* for more information.

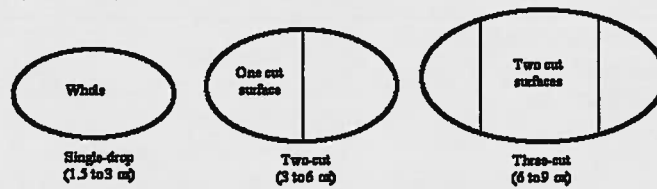
When purchasing seed, ensure that the seed grower has a good reputation. Also, check that the growing area has a history of producing quality seed. A visit to prospective seed suppliers both during the growing season and once the crop is in storage will help to assess the grower and the crop.

Determine the conditions under which the seed was produced and stored. The potato seed should not be stressed in the field. Seed should be stored at temperatures between 37 and 39°F (3 and 4°C) to ensure viability. Although potato seed may appear healthy, it may have poor germination and poor vigour if it was grown under stress, or if it was chilled or frozen in the field or in storage.

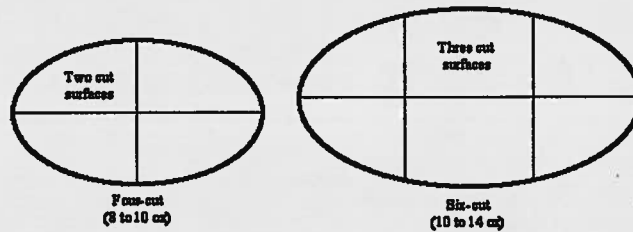
Assess the uniformity and size of the seed tubers. Performance of cut-seed pieces is affected by size of the uncut mother tubers (Figure 3.2-1). Smaller, uniformly sized mother tubers result in:

- Uniform, blocky cut-seed pieces
- A higher proportion of the most productive seed piece sizes (1.5-3 oz (43-85 g))
- Better planter performance, which contributes to high plant stands and correct spacing.

Figure 3.2-1 Seed-piece types cut from different sized mother tubers.



*Seed pieces cut from small tubers (above) are more productive on average than those cut from larger mother tubers (below)
*Growers should avoid cutting seed from tubers greater than about 8 oz (225 g) like those below

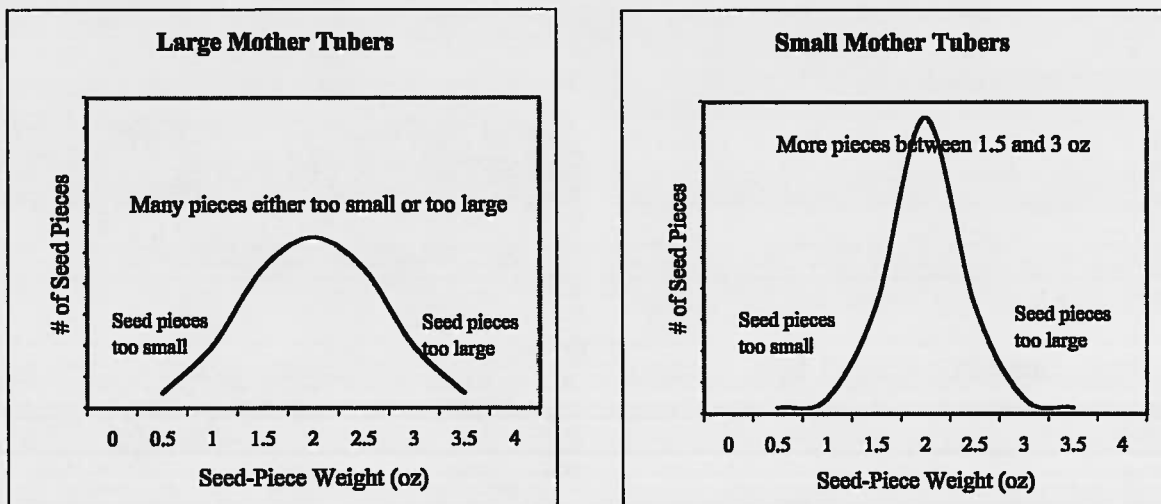


Oversize seed tubers result in many cut-seed pieces that are too large or too small (Figure 3.2-2). Small seed pieces (less than 1.5 oz or 45 g) produce weak, unproductive plants. Large seed pieces (greater than 3 oz or 90 g) are no more productive than ideal (1.5-3 oz (43-85 g)) seed pieces but cost more to plant. Variably sized and shaped seed pieces do not flow well and may not be picked up by planter picks or cups causing a reduction in plant stand.

Oversize seed tubers result in many cut-seed pieces that are too large or too small.

On average, seed pieces cut from large mother tubers (>8 oz (225g)) are not as productive as pieces of the same weight cut from smaller tubers. Seed pieces cut from larger tubers have fewer eyes and may result in blind seed pieces (no eyes), causing a reduced stand.

Figure 3.2-2 Distribution of seed piece sizes cut from large and small mother tubers (not to scale)



Negotiate terms of the seed purchase. When negotiating purchase of a seed lot, determine the method of delivery, date of delivery, desired tuber size distribution, tuber temperature and degree of sprout development.

Seed should be inspected upon delivery, and if the commercial grower has concerns about the grade, quality or physical condition, both the seed supplier and CFIA should be contacted within two days to request a re-inspection. If an inspection is requested, a CFIA inspector will carry it out within five working days of receipt of the request. The commercial grower should have unopened seed potato bags on hand or a bulk-movement certificate (in the case of bulk lots) so that the proper information can be obtained regarding the seed lot purchased. Seed tags or bulk-movement certificates are a grower's assurance that inspected seed potatoes have been purchased.

3.2.2 Whole Versus Cut Seed

There are several advantages to using whole over cut seed. Uniform lots of small, whole tubers ranging in size from 2 to 4 oz (60 to 110 g) can produce plants with:

- High vigour
- Increased stem counts
- Increased tuber set
- Uniform tubers that tend to be smaller because of the heavier set
- Less disease

Eliminating cutting reduces the risk of spreading tuber-borne diseases. Since there are no cut surfaces, seed decay is less likely; therefore, seed piece fungicides are not normally applied to whole seed. However, some growers apply fungicides for control of *Rhizoctonia* when black scurf is present on whole seed. If late blight is suspected on the seed tubers, use a seed treatment with an active ingredient effective in controlling seed-borne late blight.

Unfortunately only a small amount of whole seed is available in Western Canada. Many North American varieties do not produce large tuber sets, so it is not economical to produce whole seed tubers. Often whole seed tubers are obtained by grading out the 2 to 4 oz (60 to 110 g) tubers from the seed lot. These small whole tubers sell at a premium. The capital and operating costs of cutting must be weighed against the benefits of reduced handling, and higher cost of purchasing whole seed.

3.2.3 Sanitation, Handling and Storage of Seed Lots

Seed lots should be stored, cut and handled under sanitary conditions to prevent the spread of disease and reduce losses from disease organisms that cause rot. Sanitation consists of cleaning and disinfecting all equipment, storage, tools and pallet boxes that contact the seed potatoes. Since most disinfectants are inactivated by soil and plant debris, it is essential that this material be removed by thoroughly-cleaning equipment and storage with a pressure washer or steam cleaner before the disinfectant is applied. The seed storage and all equipment coming in contact with the seed lot should be disinfected with a quaternary ammonium compound such as Ag-Services Incorporated General Storage Disinfectant, Bardak 2210 Disinfectant Sanitizer, or DMR-23 Disinfectant. Surfaces must remain wet for at least 10 minutes for the disinfectant to destroy disease organisms.

Seed lots should be stored, cut and handled under sanitary conditions.

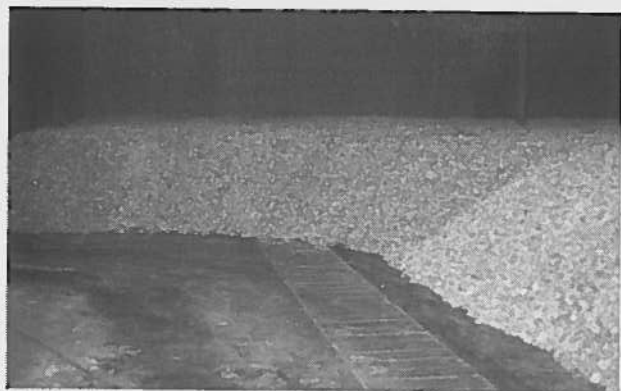
A commercial grower may be required to provide several different storage environments depending upon the time of seed delivery and the method of seed cutting used. Whole seed is typically delivered between February and April and should be stored at 37 to 39°F (3 to 4°C) and 90% R.H. until just before cutting. Growers can choose between two seed cutting methods: 1) standard seed cutting where seed is cut, treated and planted the same or next day or 2) pre-cutting, where the seed is cut, treated, stored for up to 3 weeks before planting.

The standard seed cutting method is the most common. Before cutting, seed should be warmed to 50-55°F (10-13°C) for 10 days, unless sprouts have already appeared. Warming helps break the dormancy maintained during cold storage and will accelerate emergence. If the tubers are beginning to sprout then dormancy is already broken. In this case, warm tubers to 45° F (7°C) to avoid shatter bruises caused by handling and cutting. Shatter bruises affect seed vigour and the bruises can become infected with *Fusarium* dry rot, causing poor emergence.

Bruises affect seed vigour.

The pre-cutting method helps spread out the work load at planting time, however, this practice should only be attempted if recommended temperature, airflow, and humidity can be maintained. Before cutting, seed should be warmed to 45-50°F (7-10°C) to avoid shatter bruises caused by handling and cutting. The depth of the cut-seed pile is limited by the ability of the ventilation system to maintain a proper temperature throughout the pile (Figure 3.2-3). Typically cut seed is piled no deeper than 3 to 8 feet (1 to 2.5 metres). After cutting, maintain the seed pile at 45-50°F (7-10°C), 90% R.H. for 5 days to allow the cut surfaces to suberize (heal). After suberization is complete, cool the cut seed pile to 41-46°F (5-8°C).

Figure 3.2-3 Pre-cut seed stored at a depth of less than 8 feet (2.5 m) (Courtesy of Gaia Consulting Limited)



Precautions should be taken during cutting, storage and at planting time to ensure that the cut seed pieces are not exposed to drying conditions and direct sun. Trucks, which are transporting cut seed to the field for planting, should be tarped to reduce exposure to dry air and sunlight.

3.2.4 Seed Cutting

Most European growers plant small, whole seed tubers. An increasing number of Canadian growers are planting whole seed (see section 3.2.2 *Whole versus Cut Seed*), but the most common practice is to cut whole seed tubers into smaller seed pieces.

The object of cutting is to produce uniform seed pieces with an average weight between 1.75 and 2.25 oz (50 and 65 g) (Figure 3.2-2). Growers should consult with their provincial potato specialist or processor field staff for seed size recommendations. Some varieties (Shepody and Yukon Gold) have poor eye distribution and larger seed pieces ranging from 2.25 to 2.50 oz (64 to 71 g) are recommended.

The majority of mother tubers in an uncut seed lot should be 8 oz (225 g) or less, with few tubers greater than 10 oz (225 to 300 g). Growers should maximize the number of seed pieces with single cuts, and minimize the number of tubers with two and three cut surfaces (Figure 3.2-1). This can only be accomplished if the mother seed lot does not contain many tubers over 8 oz. Variation in seed piece size results in variability of size, shape and yield of tubers from plant to plant.

**The majority of
mother tubers in an
uncut seed lot should
be 8 oz (225 g) or less.**

Seed pieces weighing less than 1.5 oz (35g) are referred to as seed chips. The chip eliminator rollers on the seed cutter should remove the seed chips because they result in unproductive plants. Improper chip eliminator roller adjustment or overloading the cutter are the main causes of excessive numbers or chips in a cut seed lot.

To reduce seed piece infections, cutter knives must be kept sharp. Sharp blades result in smooth cut surfaces that suberize (heal) quickly. Dull blades cause ragged cut surfaces that are easily infected with decay organisms. Cutters should be disinfected at least once a day or between every seed lot. Pay special attention when disinfecting the rollers as they tend to hold pathogen-laden debris. If seed is handled or cut at a temperature of 45°F (7°C) or less, the incidence of shattering bruising may increase and cause seed decay.

Seed piece fungicide treatments should be applied to all seed lots immediately after cutting. Growers must assess field location and seed source histories to determine which fungicide seed treatment to apply. Seed treatments effective against late blight are recommended if the seed originated from an area where late blight was reported. Other seed-piece treatments that control *Rhizoctonia* sp. and silver scurf are recommended when seed or field location indicates a risk for disease inoculum.

3.2.5 Determining Cut-Seed Size

Producers should manage seed cutting so the average seed piece is 2 oz (60 g) and the majority of pieces are between 1.5 and 3 oz (35-85 g) (Figure 3.2-2). Specialty market needs may demand different seed sizes and growers should verify these needs with packer or processing field staff.

**The majority cut seed
pieces should be between
1.5 and 3 oz (35-85 g).**

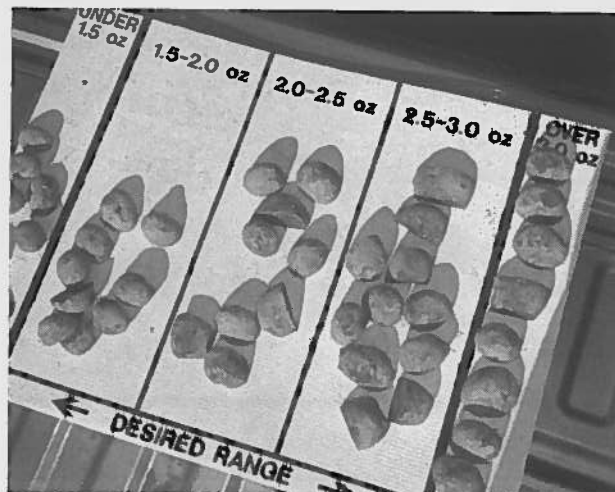
Cutter performance is determined by regularly calculating the average cut seed size and seed size distribution. At the very least, these calculations should be performed each time a new seed lot is cut. Mother tuber size, which varies with each seed lot, affects the performance of the cutter. During cutting, samples of seed pieces should be collected and individually weighed. The average size is calculated by dividing the weight by the number of seed pieces. For example, a 12.5 lb (5.4 kg) sample with 97 pieces has an average weight of just over 2 oz (60 g). The average seed size is not a good measurement of seed cutter adjustment. The average seed size may be ideal (2 oz (60 g)), but a majority of the cut seed sizes might occur outside the ideal seed size range of 1.5 to 3 oz (35-85 g). See the graph for Large Mother Tubers shown in Figure 3.2-2. Seed size distribution is the best measurement of the cutter performance. This is determined by individually weighing and arranging the seed pieces into size groups such as less than 1.5 oz (35 g), 1.5 to 3 oz (35-85 g), and greater than 3 oz (80 g) (Table 3.2-1 & Figure 3.2-4). Pieces can be further separated according to the number of cut surfaces such as whole seed, one cut surface, two cut surfaces and three cut surfaces. This grading and sorting is best accomplished by placing seed pieces on a board that has been marked similar to the example in Table 3.2-1. The size distribution data can be used to produce a bar graph. The resulting bar graph should resemble the line graph for Small Mother Tubers shown in Figure 3.2-2, where the greatest number of seed pieces occurs in the ideal size range.

Seed cutter adjustment is complicated and novice growers should seek advice from the dealer, processor or provincial potato agronomist.

Table 3.2-1 Cutter adjustment chart.

Seed type	Seed piece weight		
	< 1.5 oz (35 g)	1.5 to 3 oz (35-80 g)	>3 oz (80 g)
Whole			
1 cut surface			
2 cut surfaces			
3 cut surfaces			

Figure 3.2-4 Cut seed sorted by weight



3.2.6 Planting Rates

Average seed weight, between-row spacing and in-row spacing affect the amount of seed required per acre or hectare (Table 3.2-2). Between-row spacing varies from 34 to 38" (86-97 cm), with 36" (91 cm) being the most common in Alberta and Saskatchewan and 38" (97 cm) the most common in Manitoba. In-row spacing varies between production areas, variety and market. See section 3.3.2 *In-row Seed Spacing* to determine the appropriate in-row spacing.

Table 3.2-2 Weight of seed required for 2 oz (60 g) seed pieces planted at different in-row spacing in rows spaced 36" (91 cm) and 38" (97 cm) apart (rounded to nearest 100).

		In-row Spacing						
		6" (15 cm)	8" (20 cm)	10" (25 cm)	12" (31 cm)	14" (36 cm)	16" (41 cm)	18" (46 cm)
Seed @ 36" (91 cm) row spacing	lbs/ac	3600	2700	2400	1800	1600	1400	1200
	kg/ha	4035	3026	2690	2018	1793	1569	1345
Seed @ 38" (97 cm) row spacing	lbs/ac	3400	2600	2300	1700	1500	1300	1150
	kg/ha	3811	2914	2578	1905	1681	1457	1289

3.3 Planting Management (L. Delanoy, C. Schaupmeyer, D. Ziprick, A. Sullivan)

3.3.1 Adjusting Management According to Physiological Age of the Seed.

This chapter will be included in future manual updates.

3.3.2 In-row Seed Spacing

Potato growers on the Canadian Prairies plant potato seed pieces from 6 to 18" (15-46 cm) apart in the row. The following factors influence spacing. A brief explanation of how these factors influence in-row spacing follows:

- Variety – Different cultivars have different tuber sets and canopy development, therefore they require different in-row spacings. New producers should consult with their processor, field consultant or packer regarding spacing for a specific variety.
- Market – Seed and gourmet markets demand smaller tubers than fresh and processing markets. Smaller daughter tubers are obtained by planting seed at a closer in-row spacing, which increases competition between plants resulting in smaller daughter tubers.
- Moisture – Although difficult to predict, soil moisture status influences in-row seed spacing. Seed is planted closer under irrigated than rain-fed conditions, because the soil moisture required to support a high population of plants can be guaranteed.
- Planting date – Delayed planting shortens the growing season and in-row seed spacing may be increased to reduce competition between plants and promote tuber bulking.
- Seed size – Large seed pieces or large whole seed tubers can be spaced farther apart because they tend to produce more stems and set more tubers.
- Seed age – Physiological age is affected by field and storage conditions (stresses) during the previous growing season. To date, there is no objective method for determining physiological age. "Physiologically young" seed tubers can be planted closer together because they tend to produce fewer stems and set fewer tubers.
- Cost of Production – Close in-row spacing requires large quantities of seed. Some producers are reluctant to increase planting rates and plant at less than optimal spacing.

The following three tables (Tables 3.3-1, 3.3-2 and 3.3-3) show in-row spacing commonly used in Manitoba, Saskatchewan and Alberta.

Table 3.3-1 Commonly used in-row spacing in Manitoba.

Variety	In-row Spacing - Manitoba					
	Irrigated			Rainfed		
	Seed	Table	Processing	Seed	Table	Processing
Atlantic			10-12", 25-31 cm	10-12", 25-31 cm		12-14", 31-36 cm
Conestoga			10-12", 25-31 cm	10-12", 25-31 cm		12-14", 31-36 cm
Dakota Rose		10", 25 cm		9-10", 23-25 cm	12", 31 cm	
Dakota Pearl			11", 28 cm			
Goldrush		10", 25 cm		10", 25 cm	12", 31 cm	
Morning Gold		10", 25 cm				
Norland		11-12", 28-31 cm		11-13", 28-33 cm	12-13", 31-33 cm	
Nordonna		12", 31 cm				
NorValley			10", 25 cm			12", 31 cm
Penta		11-12", 28-31 cm				
Pontiac		9-10", 23-25 cm		9-10", 23-25 cm	9-10", 23-25 cm	
Ranger Russet	10-12", 25-31 cm		12-15", 31-38 cm			
Russet Burbank	10-11", 25-28 cm	12-15", 31-38 cm	12-18", 31-41 cm	12", 31 cm	15-16", 38-41 cm	17-18", 43-46 cm
Russet Norkotah		11-12", 28-31 cm				
Sangre		10-12", 25-31 cm		10-12", 25-31 cm	12-14", 31-36 cm	
Snowden			12", 31 cm			
Shepody	7-9", 18-23 cm		11-14", 28-36 cm	9-10", 23-25 cm		14-16", 36-41 cm
Viking		8-10", 20-25 cm		8-10", 20-25 cm	9-11", 23-28 cm	
Yukon Gold		8-9", 20-23 cm			9-10", 23-25 cm	

Table 3.3-2 Commonly used in-row spacing in Saskatchewan.

In-row Spacing - Saskatchewan				
Variety	Irrigated		Rainfed	
	Seed	Table	Seed	Table
Alpha	6-8", 15-20 cm		8-10", 20-25 cm	
Atlantic	6-8", 15-20 cm		8-10", 20-25 cm	
Cal White	6-8", 15-20 cm		8-10", 20-25 cm	
Norland	6-8", 15-20 cm	8", 20 cm	9-11", 23-28 cm	10", 25 cm
Ranger Russet	7-9", 18-23 cm		9-11", 23-28 cm	
Russet Burbank	7-9", 18-23 cm		9-11", 23-28 cm	
Russet Norkotah	6-8", 15-20 cm	8", 20 cm	7-9", 18-23 cm	10", 25 cm
Sangre	6-8", 15-20 cm	8", 20 cm	7-9", 18-23 cm	8", 20 cm
Shepody	6-8", 15-20 cm		7-9", 18-23 cm	
Yukon Gold	6-8", 15-20 cm	8", 20 cm	7-9", 18-23 cm	10", 25 cm

Table 3.3-3 Commonly used in-row spacing in Alberta.

In-row Spacing - Alberta					
Variety	Irrigated			Rainfed	
	Seed	Table	Processing	Seed	Table
Atlantic	6", 15 cm		8-9", 20-23 cm	6-10", 15-25 cm	
Alpha	6", 15 cm			6-10", 15-25 cm	
Bintje	6", 15 cm	8-10", 20-25 cm		6-10", 15-25 cm	10-12", 25-31 cm
Norland	6", 15 cm	8-10", 20-25 cm		6-10", 15-25 cm	8-11", 20-28 cm
Ranger Russet	6-7", 15-18 cm	11-12", 28-31 cm	11-12", 28-31 cm	6-10", 15-25 cm	12-14", 31-36 cm
Russet Burbank	6-7", 15-18 cm	11-13", 28-33 cm	11-13", 28-33 cm	6-10", 15-25 cm	12-14", 31-36 cm
Russet Norkotah	6", 15 cm	10-11", 25-28 cm		6-10", 15-25 cm	12-14", 31-36 cm
Shepody	6", 15 cm		10-11", 25-28 cm	6-10", 15-25 cm	
Umatilla	6", 15 cm		11-13", 28-33 cm	6-10", 15-25 cm	
Yukon Gold	6", 15 cm	9-11", 23-28 cm		6-10", 15-25 cm	10-12", 25-31 cm

3.3.3 Planting For Better Stand, Yield and Quality

Potato fields that have been planted properly will produce complete stands of uniform plants (Figures 3.3-1). With adequate mid-season management, they will produce high yielding, top quality, and profitable crops.

Plant misses (Figure 3.3-2) result from seed decay, planter skips or blind seed pieces. A plant adjacent to a "miss" produces higher than average yield. However, the increase is not sufficient to compensate for the zero yield of the missing plant. Plants adjacent to misses generally produce oversize tubers that bruise more easily and are more subject to hollow heart, knobs and deformities.

Production costs for a field with a poor stand of variable plants are the same as those for a field with a high stand of productive plants.

Figure 3.3-1 Good plant stand (Courtesy of Clive Schaupmeyer)



Figure 3.3-2 Poor plant stand (Courtesy of Clive Schaupmeyer)



Soil Temperature at Planting

Planting into soil of the proper temperature is important to ensure a healthy stand of potatoes, especially when planting fresh cut seed. Wound healing of fresh cut seed takes place when soil temperatures are between 55-60°F (13-16°C). This temperature also encourages quick emergence without promoting the growth of seed piece decay organisms. Planting unhealed seed pieces in cold soils delays emergence and increases the risk of seed piece decay resulting in a poor plant stand.

Planter Operation

There are four types of planter mechanisms used in large-scale planters: pick (Figure 3.3-3), cup (Figure 3.3-4), belt and vacuum cup (Figure 3.3-5).

Figure 3.3-3 Pick planter mechanisms (Courtesy of Clive Schaupmeyer)



Figure 3.3-4 Cup planter mechanisms (Courtesy of Leonard Rossnagel)



Figure 3.3-5 Vacuum cup planter mechanisms (Courtesy of Clive Schaupmeyer)



A planter must be maintained in good working order. Planter models have different maintenance and adjustment needs and growers should seek adjustment and operating advice from manufacturers, machinery dealers or agronomy consultants.

The following are important to planter operation:

- To assure planter accuracy and to avoid misses, optimum ground speed must be determined for every seed lot
- For most pick and cup planters, the optimum speed is between 2.5 and 3.5 mph (4-5.6 km/h)
- Ground speeds may be slightly faster if in-row spacing are wider
- Vacuum planters generally plant well at higher speeds, up to 4 mph (6.4 km/h)
- Proper seed cutting. Irregular seed piece sizes affect planter performance. Planter accuracy is increased when seed piece size is uniform
- Picker (seed) bowls should normally have 5 to 10 lbs (2.25-4.5 kg) of seed in them at all times
- Cup planters may require matching cup size to average seed size

Planter Maintenance

Planters must be maintained according to the manufacturer's guidelines. Full details cannot be provided here, however primary concerns include:

- Pick planter springs must be replaced when weakened
- Dull picks must be replaced when planting accuracy declines
- Vacuum planter suction cups and air systems must be cleaned

Planter Calibration

Planters should be calibrated for each seed lot by planting seed for a short distance and then checking for misses and accuracy of spacing. Seed pieces are exposed by raking hills away from at least 20 feet (6 m) of row (Figure 3.3-6). Planter mechanisms can vary from row to row in a multiple row planter; therefore, all rows must be checked for accuracy.

Assess planter performance by measuring the spacing between seed pieces and counting the number of misses and doubles. As a general rule, at least 80% of the seed pieces should be within 2" (5 cm) of the narrow in-row spacing and 3" (7.6 cm) for wider in-row spacing. For example, if the target spacing is 12" (30 cm), the spacing between seed pieces should range from 10 to 14" (25-36 cm), while for a target spacing of 18" (45.7 cm), the range should be 15-21" (38-53 cm). Doubles and misses should be minimal. The plant population should be above 91%, and skips no greater than 5%. If spacing is inaccurate, and doubles and misses excessive, then planter speed should be changed and planter performance retested.

Figure 3.3-6 Calibrating the planter – Evaluating seed spacing (Courtesy of Clive Schaupmeyer)



Planting Depth

On the prairies, most producers plant seed pieces from 4 to 7" (10-18 cm) below the peak of the planter hill. Plants from seed pieces planted close to the surface will emerge earlier. However, soil temperatures near the surface may be too high for maximum tuber set. Shallow planting will cause the tubers to set high in the hill, increasing the risk of tuber greening and frost. Depending on soil moisture and temperatures, seed pieces that are planted too deep may have a higher incidence of decay. Planting into cold soil can increase the incidence of *Rhizoctonia* canker on stems and stolons resulting in poor emergence and low tuber set.

3.4 Field Selection, Soil Management and Fertility

3.4.1 Field Selection (P. Haluschak, C. McKenzie, K. Panchuk)

Field selection is one of the most important contributors to high potato yield and quality. Potatoes are a high-value crop and should only be grown on the best land available. Several factors must be considered before a field is selected for potatoes. Some factors such as drainage and herbicide residues can have a significant impact on yield while other factors, such as soil texture and crop rotation, have a lesser impact.

Crop Rotation

Potatoes must be rotated with other crops to slow the accumulation of diseases and reduce the impact of insects such as Colorado potato and flea beetles. When planning crop rotation two factors must be considered:

1. The length of rotation
2. The rotational crop

The length of time between potato crops is determined by disease and insect levels (Table 3.4-1). A two or three year rotation adequately controls most diseases as well as reduces the population of Colorado potato beetles and flea beetles. Other diseases such as *Verticillium* wilt, require longer rotations. A four-year rotation is strongly recommended. Shorter rotations result in a build-up of soil borne diseases and a condition called early dying. This condition can result in yield losses as high as 30%.

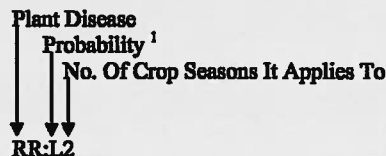
Cereal grains and corn are generally the best to use in the three years between potato crops. However, the decision about which crop to use in rotation must be made considering:

- The similarity of diseases between potatoes and the rotational crop
- Soil conservation (i.e. organic matter, surface cover, trash, etc.)
- The herbicides used in the rotational crop (section 3.4.2 *Herbicide Residues and Re-cropping to Potatoes*)

Table 3.4-1 Crop rotation chart

Previous Crop	Disease Risk	Previous Crop	Disease Risk
Barley	ND	Flax	RR:L2, SP:L1
Oats	ND	Lentils	RR:L2, SP:L1, SD:L3
Fall Rye	ND	Mustard	RR:L2, SP:L1
Spring Rye	ND	Potatoes	SP:H1, VW:H4, EB:H1, RR:H3, SD:L3
Triticale	ND	Canola	RR:L2, SP:L1, SD:L3
Wheat	ND	Soybeans	RR:L2, SP:L1, SD:L3
Winter Wheat	ND	Sugarbeets	RR:L2, SP:L1
Buckwheat	RR:L1, SP:L1	Sunflowers	RR:L2, SP:L1, VW:H4, SD:L3
Canary Seed	ND	Corn	ND
Fababeans	RR:L2, SP:L1, SD:L3	Forage Grasses	ND
Field Beans	RR:L2, SP:L1, SD:L3	Alfalfa	RR:L2, SP:L1, VW:H4
Field Peas	RR:L2, SP:L1, SD:L3	Sweet Clover	RR:L2, SP:L1, VW:H4

Key:



Plant Disease -- Code/Description

- EB Early Blight
- SD Sclerotinia Disease
- SP Seed Piece Decay
- VW Verticillium Wilt
- ND No Disease
- RR Root Rot

¹ The letters L, M and H denote risk for disease. L and M are low and moderate risk, where the crop is somewhat resistant and receives only slight damage. The probability that damage is likely to occur is less than 25%. With H or high-risk diseases, losses over 25% can occur.

The above example "RR:L2" indicates a low probability of root rot for 2 years.

Weather conditions play an important part in disease development. Most diseases are more severe in wet seasons; however, a few types of root rots are most severe under dry conditions. Very favourable conditions for disease development may cause a disease that is a low risk to become a high risk. Conversely, high-risk diseases may not materialize if conditions are unfavourable for disease development. The disease problems occurring on at least the previous four crops should be taken into consideration when planning a crop rotation. Continuous planting to the same crop can eventually cause low risk disease problems to build up resulting in severe crop losses.

Soil Texture

Mineral particles in soil are grouped into sand (2 - 0.05 mm in diameter), silt (0.05 - 0.002 mm) and clay (less than 0.002 mm in diameter). The proportion of sand (S), silt (Si) and clay (C) particles present in a soil is referred to as texture (Figure 3.4-1). The presence of larger particles in soil is recognized as gravel, cobbles or stones. Soil texture strongly influences the infiltration of water, the ability of the soil to retain moisture (water holding capacity), its general level of fertility, the tendency to form clods and ease of cultivation. The combination of similar textural classes forms textural groups (Table 3.4-2).

Well-drained soils with loamy sand to sandy loam textures are considered most suitable for potato production. These soils have an adequate capacity to retain water, provide sufficient aeration for root and tuber development and favourable conditions for planting and harvesting. Sound management practices are required to minimize the potential for wind erosion on these soils.

Farmers are successfully producing potatoes on silt loam, sandy clay loam, silty clay loam and clay loam textural classes (Figure 3.4-1) even though these soils are not considered ideal for potato production. These finer texture soils are prone to water erosion in undulating landscapes, poor to fair internal drainage and soil clod formation if tilled when wet.

A soil that contains a large amount of clay (fine textured soil with more than 35% clay) becomes sticky when wet and lumpy when dry. If this soil is too dry at harvest, it is difficult to separate the soil clods (aggregates) from the potatoes. Tubers harvested from a wet clay soil will also require washing to remove soil particles. These soils are not considered suitable for commercial potato production.

Figure 3.4-1 Diagram showing the percentages of clay, silt and sand in the main soil textural classes (Courtesy of Manitoba Agriculture and Food).

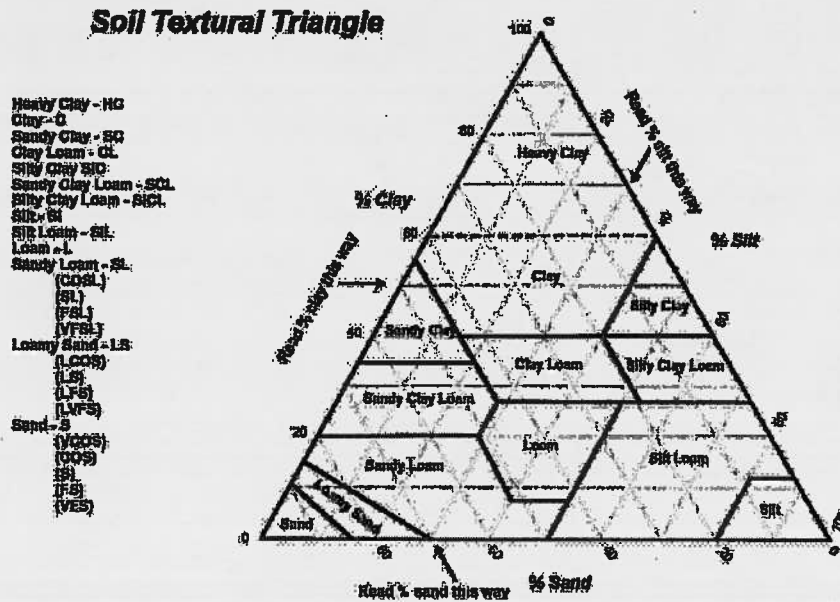


Table 3.4-2 Soil Textural Groups, Classes and Symbols.

Texture Group		Texture Class	Texture Class Symbol	
Very Coarse		Sand	S	
Coarse		Loamy Sand	LS	
Moderately Coarse		Sandy Loam	SL	
Medium		Loam	L	
		Silt loam	SiL	
		Silt	Si	
		Sandy clay loam	SCL	
		Clay loam	CL	
		Silty clay loam	SiCL	
Fine		Sandy clay	SC	
		Silty clay	SiC	
		Clay	C	
Very Fine		Heavy	Heavy clay (>60 % clay)	HC

Topography

Topography refers to the percent slope and the pattern or frequency of slopes in different directions in a field. The steeper the slope, the less suitable the field is for potato production. Surface runoff occurs when the amount of water from rainfall or an irrigation application exceeds the rate of infiltration, which is strongly influenced by soil texture. The risk of soil loss is proportional to the length of the slope and the severity of the grade. Medium and fine textured soils are most susceptible to water erosion in sloping landscapes.

Soil Salinity

Salinity refers to the presence of water-soluble salts in soil. Saline refers to a soil condition where water-soluble salts are present in sufficient amounts to affect crop growth. Salinity is measured as the electrical conductivity (EC) and is expressed as deciSiemens/metre (dS/m) or microSiemens/centimetre. The accepted standard is dS/m, however all units of measure are equal. Salinity levels range from less than 4 (non-saline), 4-8 (slightly saline), 8-15 moderately saline and >15 strongly saline. Soils with a reading of less than 4 are most suitable for potatoes. On moderately saline soils, growth and yield of potatoes can be reduced. Leaves may be darker and have burned edges. Plants growing in saline soil are unable to draw water and nutrients, particularly phosphorus, from the soil.

Moderate salinity will reduce growth and yield of potatoes.

Potato production plays a role in soil salinization. The addition of high amounts of irrigation water and fertilizer add significant quantities of salt to the soil. Early detection of salt-affected areas is critical in preventing

crop damage or an increase in salinity. A field assessment determining the degree of salinity can be accomplished by soil sampling and analysis or by mapping with an EM38 electromagnetic induction meter. If salinity is a concern, assessments should be conducted every 5 years to determine if salinity is increasing over time. If salinity is detected, growers should implement appropriate water management and cropping practice strategies to improve the productivity of the soil. Prairie Farm Rehabilitation Administration and private soil laboratories provides these service.

Soil pH

Soil reaction, or pH, refers to the degree of acidity or alkalinity. A pH between 7.1 and 14 indicates an alkaline condition, a higher pH value indicating a greater alkalinity. A pH less than 7.0 indicates acidity and the lower the pH the greater the acidity. Most nutrients are readily available in soils with a pH range of 6 to 7, with a decrease in availability at soil pH above or below this range. Strongly acid soils have low extractable calcium and magnesium, a high solubility of aluminium, iron, and boron, and a low solubility of molybdenum. At the other extreme are alkaline soils. Calcium, magnesium and molybdenum are abundant in these soils with little or no toxic aluminium. Phosphorous availability may be greatly reduced at both very low and very high pH values due to phosphate fixation.

Soils below pH 5.2 (slightly acid) and above 8.3 (slightly alkaline) are not recommended for potatoes.

Soil Organic Matter

Organic matter is derived from the residues of decaying organisms such as plants, animals, insects and microorganisms. Organic matter is a very important component of soil that stores and supplies plant nutrients, holds soil particles together, improves tilth and reduces the risk of erosion. Organic matter increases soil porosity and promotes water infiltration. To maintain organic matter, the rate of addition of crop residues must equal the rate of decomposition. Continuous production of row crops such as potatoes, beans or sugar beets usually results in a rapid decline of soil organic matter because the total amount of crop residue returned to the soil is low. The level of organic matter in the soil can be maintained by crop rotations that include perennial forage crops, by adding manure, or by the production of cereal crops where residues are not removed and minimum tillage is practised.

Soil Compaction

Heavy equipment traffic and excessive tillage cause soil compaction. Soil compaction can be identified by the following symptoms:

- Excessive clod formation
- Slow water infiltration, especially in wheel tracks
- Distorted root and tuber growth and premature wilting from shallow rooting

Potatoes are sensitive to the physical condition of the soil. Dense or compacted soil interferes with root penetration as well as water and nutrient uptake. The plant will display symptoms of stress and the yield can be reduced. Compacted soil zones can be identified by carefully inspecting root growth patterns and soil texture in a 3-foot (0.9 m) deep trench.

Minimize compaction by reducing the amount of traffic or weight in the field. Avoid unnecessary vehicle traffic, tillage or hilling. The effect of compaction can be reduced by the use of tillage equipment that loosens soil to approximately 14 inches (35 cm) without inversion of soil layers. Subsoil tillage is expensive because of the high capital and operating costs of the equipment. A potato grower should confirm that compaction is causing production problems before investing in sub-soiling equipment.

Soil Drainage

Soil drainage refers to the ability of water to flow downward through soil. Well-drained soils have sufficient surface runoff and/or downward movement of water through the soil to result in relatively short periods of saturation. Poorly drained soils have a greater frequency and duration when the soils are saturated in all

or part of the root zone. Soil drainage may be influenced by topography, uniformity of soil materials, proximity to the water table and climate.

Excessive water in the soil limits the free movement of the oxygen necessary for healthy root and tuber development. Excessive soil moisture increases the incidence of fungal diseases, and delays spring tillage, planting and harvesting. In extreme cases, excessive soil moisture causes tuber rot leading to the loss of the entire crop. Improved surface and sub-surface drainage can reduce the effect of excessive moisture conditions in imperfectly and poorly drained soils.

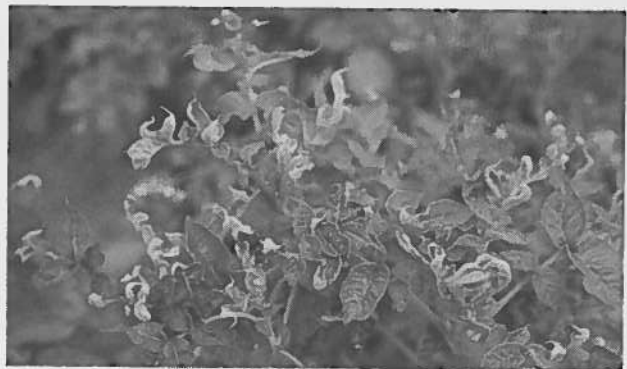
Stoniness

Soils that are free of stones or coarse fragments are most suitable for potato production. Factors such as size and abundance of stones must be considered when assessing a field for potato production. Large stones and boulders in a field make tillage difficult and can damage harvest equipment. Stones increase the chance of potato bruising during harvest. Stones cause a problem in seed production if they get into the cutter.

3.4.2 Herbicide Residues and Re-cropping to Potatoes (B. Geisel, C. Neeser)

Herbicide residues from previous crops grown in rotation with potatoes can affect yield and tuber quality factors such as size, shape and specific gravity (Figures 3.4-2, 3.4-3 and 3.4-4). The vigour of seed produced from fields with an herbicide residue can also be negatively impacted. The herbicide residue is concentrated in the tuber resulting in poor seed performance. Herbicides that could potentially harm potatoes are listed in Table 3.4-3.

Figure 3.4-2 Damage to foliage caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)



All farmers should keep detailed records of herbicide use for each field. When leasing or purchasing new land, review the field history for potential herbicide residues.

Cultural and environmental factors, as well as the properties of the herbicide, influence the persistence of herbicide residues in the soil. These factors (discussed below) are highly variable between fields and growing seasons. Soil texture and moisture are the two most important factors affecting the re-cropping interval.

Organic Matter, Soil Texture and Moisture

The effect of soil organic matter, texture, moisture and microbial activity on herbicide residue is interrelated. Sandy soils have a lower percentage of organic matter and soil moisture, whereas clay soils have a higher percentage of organic matter and soil moisture. The interval between the application of the herbicides in Table 3.4-3 and re-cropping to potatoes is shorter in loams than sands because 1) finer textured soils have more moisture, which increases microbial activity (see below) and 2) herbicide residues bind to organic matter and clay particles in loams, causing them to be less biologically active.

Microbial Activity

Soils with a higher organic matter and clay content tend to have a higher moisture holding capacity. Generally, the population of soil microbial flora and fauna is larger and more active in soils with a higher soil moisture level, organic content and temperature. The breakdown of herbicide residues are accelerated in situations where microbial populations flourish.

Precipitation and Irrigation

The amount and distribution of moisture (precipitation plus irrigation) received during the growing season(s) between the herbicide application and re-cropping to potatoes is the most important factor determining the rate of residue degradation. Degradation is accelerated in soils with high moisture content. Higher precipitation and/or irrigation amounts increase available soil moisture, which in turn increases soil microbial activity and the rate of herbicide breakdown.

Farmers should be very cautious if the growing season(s) following the application of an herbicide known to cause injury received:

- below average precipitation, or
- average to above average precipitation, but poor seasonal distribution causing short periods of drought.

Either of these situations will prolong the persistence of herbicide residues.

Figure 3.4-3 Damage to roots and stolon caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)



Soil pH

Degradation of residues by hydrolysis is highly pH dependent for some herbicides (i.e. sulfonylureas). A pH less than 7.0 will accelerate sulfonylurea herbicide degradation by hydrolysis in conjunction with microbial activity and should be considered in estimating the re-cropping interval. The effect of pH is minor compared to factors such as soil texture and precipitation/irrigation.

Chemical Application

The timing of chemical application, the rate at which the chemical was applied, whether any overlaps occurred during spraying and whether chemicals from the same family group were applied in consecutive years are all important factors which will influence residue persistence.

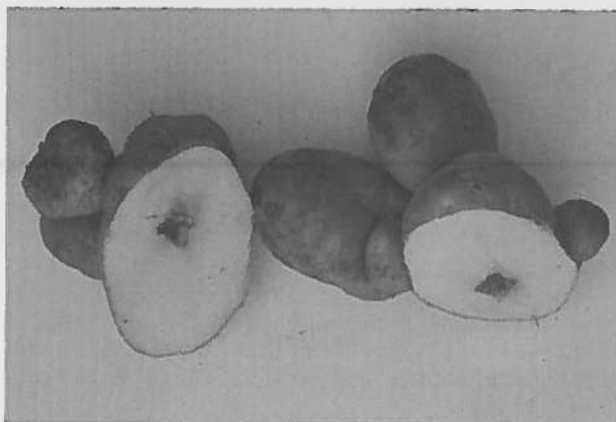
Applying herbicides later in the growing season (mid – late June) will increase the risk of herbicide damage. When an herbicide is applied late in the season, soil microbes have less time for chemical degradation before freeze-up, particularly under rain-fed crop production.

Herbicide labels often recommend different application rates to control different weed species or levels of infestation. Applying at the higher rate will lengthen the safe re-cropping interval.

Overlaps of herbicide applications at the end of the sprayer boom or at headlands and “spot” spraying of weed patches with higher than recommended label rates will increase herbicide persistence. This results in a greater risk when re-cropping to potatoes.

Applying herbicides from the same chemical family in consecutive years also increase the risk of residue damage when re-cropping to potatoes.

Figure 3.4-4 Misshapen tuber and hollow heart caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)



Definitions of Terms Used in Table 3.4-3 List of Herbicides with Potato Re-cropping Restrictions

Re-cropping Interval refers to the length of time between the application of the herbicide and re-cropping to potatoes. One year after application refers to one cropping year. For example if an herbicide was applied in 2000 and the recommendation is to not re-crop to potatoes for one year after application then do not re-crop until 2002.

A **field bioassay** is a test strip of potatoes grown to maturity in a field to determine whether herbicide residues will affect a crop. For example, 10 months after a particular herbicide was applied, a test strip of potatoes could be grown to determine whether potato yield and/or grade will be affected 22 months after initial herbicide application.

Select an area of the field that mostly closely approximates the soil conditions of the entire field. Test strips should be planted perpendicular to the direction in which the site was sprayed using standard planting equipment and following normal cultivation practices. Test strips should be of

sufficient length to transect several spray swaths and should be at least one planter width wide. Insects and foliar diseases, such as late blight, must be controlled in order to accurately assess the affect of residues on yield and grade. Reliability of the bioassay results will increase with the number and length of test strips planted. The test strips should be examined for possible stand reductions and other symptoms of injury such as reductions in plant vigour, yield and grade. If any injury, stand reduction or yield reduction occurs, do not plant potatoes until another bioassay is conducted the following growing season. It should be noted that yield losses within a test strip might not be measurable unless the yield can be compared to an untreated area adjacent to the treated test strip.

A **laboratory bioassay** is the growing of plants in a greenhouse or growth chamber to determine if herbicide injury will occur. Soil samples are collected from a field suspected of having an herbicide residue and submitted to a laboratory for a bioassay test. The lab will grow a species of plant known to be sensitive to a specific herbicide or class of herbicides in the sample soil, along with the crop to be planted. If injury occurs to the test bioassay plants, then the potential exists for significant field crop injury. Contact the Alberta Research Council for details regarding soil sampling procedure and prices:

Alberta Research Council
Crop & Plant Management
Hwy 16A & 75 Street
Vegreville, AB
T9C 1T4

Contacts: Harold Feddema at (780) 632-8238 or
Sandi Checkel at (780) 632-8217

Website:

<http://www.agric.gov.ab.ca/agdex/600/609-1.html>

Table 3.4-3 List of herbicides with potato re-cropping restrictions².

Trade Name - Manufacturer	Group	Active Ingredient	Potato Re-cropping Restriction
Amitrol 240 - Nufarm	11	amitrole	Residues may affect crops for 8 months following application.
Atrazine - Syngenta Laddok - BASF Primextra - Syngenta	5	atrazine	Sensitive crops such as potatoes may be affected 22 OR MORE months after application.
Curial M - Dow AgroSciences Prestige - Dow AgroSciences Prevail - Dow AgroSciences Eclipse - Dow AgroSciences FlexMax Ultra - BASF	4	clopyralid + MCPA	Do not grow potatoes until 22 months after application.
Lontrel - Dow AgroScience	4	clopyralid	Do not sow potatoes into fields treated with Lontrel until the third growing season after application.
Banvel II - BASF Dyvel II - BASF Dyvel DS - BASF	4	dicamba	Do not grow potatoes until 22 months following an application if greater than 240 g/acre active or if applications are made after September 1 or if dry weather persists after application.
Muster - Dupont Muster Gold - Dupont	2	ethanetsulfuron methyl	Do not grow potatoes until a bioassay is conducted at 22 months after application.
Accent - Dupont	2	nicosulfuron	Do not grow potatoes until a field bioassay is performed.
Amber - Syngenta Unity - Aventis	2, 6	triasulfuron	Note: Not for use in Manitoba. In other provinces do not grow potatoes until a field bioassay is performed.
Velpar - Dupont	5	hexazinone	Insufficient information available. Velpar residues will persist for 2 or more years after application. Do not grow potatoes until a field bioassay is performed.
Attain - Dow AgroSciences	4	fluroxypyr	Do not grow potatoes until 22 months after application.
Assert - BASF	2	imazamethabenz	Do not grow potatoes until a field bioassay is performed.
Odyssey - BASF	2	imazamox & imazethapyr	Do not grow potatoes until a field bioassay is performed.
Pursuit - BASF	2	imazethapyr	Do not grow potatoes until a field bioassay is performed.
Ally Toss-N-Go - Dupont Escort - Dupont	2	metsulfuron methyl	DO NOT APPLY on farms where potatoes are included in the rotation.
Tordon 202C - Dow AgroSciences	4	picloram	DO NOT APPLY on farms where potatoes are included in the rotation.
Accord - BASF	4	quinclorac	DO NOT APPLY on farms where potatoes are included in the rotation.
Princep - Syngenta Simazine - United Agri Products	5	simazine	Do not sow treated field to any crop until 22 months after application.
Sundance - Monsanto Anthem - Monsanto	2	sulfosulfuron	Sundance - For use in Manitoba only. Only apply on soils with greater than 4% organic matter. Allow at least 22 months following application and conduct a field bioassay prior to planting. Anthem - For use on Brown and Dark Brown Soils of Saskatchewan only. Allow at least 22 months following application and conduct a field bioassay prior to planting.
Frontline - Dow AgroSciences Spectrum - Dow AgroSciences	2, 4	florasulam	Do not grow potatoes until a field bioassay is performed.
Reflex - Syngenta	14	fomesafen	This product is registered for use in the Red River Valley of Manitoba only. Do not grow potatoes until a field bioassay is performed.
K2 - Dupont	2	thifensulfuron methyl + tribenuron methyl	Do not grow potatoes until a field bioassay is performed.

² The above list may be incomplete because of the registration of new herbicides since this document was published.

Consult with the chemical manufacturers label before making re-cropping decisions.

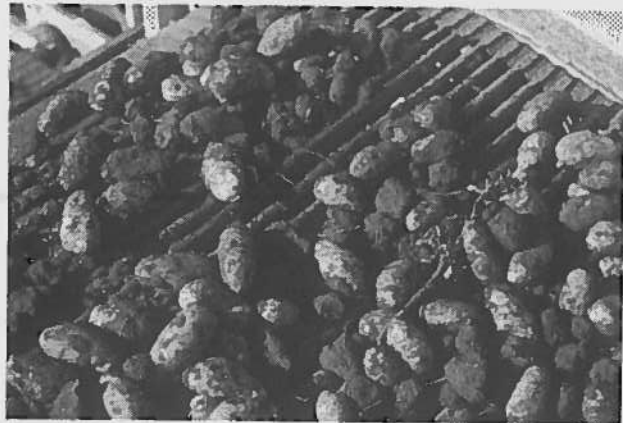
3.4.3 Field Preparation (B. Geisel, L. Delanoy)

Heavy equipment traffic and excessive tillage cause soil compaction, which reduces potato yield and quality (see *Soil Compaction* in section 3.4.1 *Field Selection*). Minimize compaction by reducing the amount of traffic or weight in the field. Do not carry out unnecessarily tillage operations.

Potato producers use a wide range of tillage equipment and techniques to prepare the potato seed bed. The variation in tillage practices results from the wide range of soil types used in potato production and the variety of tillage implements available for soil preparation. Regardless of the tillage system used, it must meet the following criteria:

- Incorporate trash -- A balance must be maintained between incorporating an adequate amount of crop trash to facilitate planting while maintaining sufficient soil trash cover to prevent wind erosion. Crop residue must be incorporated into the soil to allow for trouble free planting. The amount of tillage required to do this will depend upon the soil type, the type of crop preceding potatoes and the ability of the planter to perform properly in crop residues. Tillage should not incorporate so much crop residue that the soil is susceptible to wind erosion. See section 3.4.4 *Soil Conservation* for more details regarding soil erosion.
- Produce good tilth without drying out the soil or producing soil clods - Tillage should produce enough loose soil to allow the planter shoe to penetrate to the desired depth and to provide the tiller discs with enough loose soil to construct a proper hill over the seed. Tillage that dries out the soil surface will reduce emergence and vigour. Tillage of finer texture soil types (loams) with the wrong implement or at the wrong soil moisture content will produce clods that remain intact throughout the growing season and into harvest. Soil clods are difficult to separate from the potatoes on the harvester thus reducing efficiency and increasing cost (Figure 3.4-5). Hard dry clods that come into contact with the tubers on the harvester and other handling systems will cause blackspot bruising. For more information on bruise prevention see section 3.8.4 *Bruise Prevention*.
- Herbicide incorporation - Sufficient tillage is required to properly incorporate pre-emergence herbicides. Follow the chemical manufacturers' instructions regarding the tillage method required for herbicide incorporation.

Figure 3.4-5 Soil clods on conveyor (Courtesy of Gaia Consulting Limited)



Field preparation should be performed in as few operations as possible. Excessive tillage will increase the cost of production, the likelihood of wind erosion and the amount of soil compaction. Below is a short description of three common tillage methods used on the Prairies.

Conventional

Operations such as deep tillage or discing are performed in the fall and cultivation is performed prior to planting in the spring.

Advantages:

- Inexpensive -- Low capital and operating costs
- High capacity -- 15-25 acres/hour (6-10 ha/hr) depending upon tractor speed and width of implement
- Preserves surface trash depending upon number of operations and shovel design

Disadvantages:

- Can produce soil clods, depending upon soil conditions at the time of tillage

Rotary Power Cultivator

In Manitoba and Saskatchewan, producers growing potatoes on loam and clay loam soils use conventional tillage (deep tiller or double disc) in the fall. In the spring, a single pass with a rotary power cultivator prepares the soil before planting (Figure 3.4-6). The rotary cultivator is a power cultivator that stirs the soil laterally rather than mixing the soil vertically like a rotovator.

Advantages:

- Clod free soil bed
- Preserves surface trash
- Preserves moisture, especially important in rain-fed production

Disadvantages

- Low capacity – 5-7 acres/hour (2-2.8 ha/hr) with a 20-foot (6 m) implement depending upon soil conditions and texture
- Costly – High capital and operating expenses
- Poor weed control – has a tendency to transplant rather than destroy weeds

Figure 3.4-6 Rotary power cultivator (Courtesy of Gaia Consulting Limited)



Disadvantages:

- Costly – high capital cost
- Requires a large tractor (>300 h.p.) in the fall

Figure 3.4-7 Fall bedding and reservoir tillage implement (Courtesy of Gaia Consulting Limited)



Figure 3.4-8 Reservoirs constructed in the fall. (Courtesy of Gaia Consulting Limited)



Fall Bedding and Reservoir Tillage

A fall bedding and reservoir tillage (diking) implement performs both the tillage and hilling operations. In the fall prior to spring planting of potatoes, the field is tilled with a deep tiller or a double disc. Next, deep subsoil tillage is performed, hills are constructed and reservoir dikes or depressions are formed between the rows (Figures 3.4-7 and 3.4-8). The reservoirs capture water from melting snow and increase soil moisture. In spite of the aggressive fall tillage, surface trash cover is preserved, reducing the potential for wind erosion. In the spring, the hills are packed with rolling wire baskets to break up soil clods that survive the freezing and thawing cycles over the winter, the hills are reshaped and the reservoirs are removed. The potatoes are planted directly into the pre-formed hills. After planting, the final hilling is carried out and new reservoirs are formed between the rows.

Advantages:

- High Capacity – 8-11 ac/hr (3-4.5 ha/hr) in fall, 15 ac/hr (6 ha/hr) in spring
- Hills warm up faster in the spring
- Increased water retention
- Reduces run-off and drown-out in low areas as a result of precipitation or irrigation
- More even moisture between high and low areas of the field
- Clod free soil preparation
- Preserves soil trash

3.4.4 Soil Conservation (B. Geisel, B. Hunt)

Soil Erosion

Wind and water erosion resulting in serious soil losses (Figure 3.4-9) can be a problem on the prairies due to a combination of climate, soil type, growth characteristics of the potato plant and management practices used in potato production:

- Most potato producing areas, especially southern Alberta, experience high winds when the fields are exposed and vulnerable to erosion.
- Potatoes are usually grown on sand or sandy loam soils, which are susceptible to wind erosion.
- The risk of wind erosion is greater when planting light textured soils to potatoes rather than cereals. Potatoes do not emerge from the soil for 3 weeks after planting and it takes an additional 2 - 3 weeks before there is sufficient vegetative growth to prevent erosion.
- Tillage, crop rotation and harvest practices used in potato production can leave fields without adequate crop trash cover for many months of the year. In the fall and spring prior to potatoes, some crop residue must be incorporated into the soil to allow for trouble free planting. Often there is too little trash cover remaining to prevent erosion. The potato harvest is similar to an aggressive tillage operation, which disturbs the soil, leaving little crop residue cover to prevent erosion.

Figure 3.4-9 Soil erosion from a potato field without adequate crop residue cover (Courtesy of Gaia Consulting Limited)



Soil formation is a natural and ongoing process, but if wind erosion is visible, soil losses are greater than the rate of soil formation. One storm that removes a 1/4 inch (7 mm) layer of soil results in the loss of 44 tons per acre (40 tonnes per ha) of top soil and will require at least 10 years to be replenished; assuming no further erosion occurs.

The loss of topsoil through wind erosion reduces yield potential by negatively affecting fertility, physical structure, tilth, permeability and water holding capacity. In addition, eroded soil from agricultural land can fill ditches reducing the effectiveness of drainage systems. In some jurisdictions, like Alberta, a fine can be imposed if a farmer fails to control erosion, and the expense of cleaning out the drainage or irrigation ditches is the responsibility of the landowner.

The erosion prevention practices listed below are discussed under three headings:

1. Potato field preparation and planting
2. Potato harvest and post-harvest
3. Long-term strategies

Field Preparation and Planting

In the fall, the combine should be outfitted with a straw and chaff spreader to distribute residue evenly across the field. Additional flailing or harrowing may be necessary to help chop and distribute the crop residue. Even distribution of the straw allows the farmer to use fewer and less aggressive tillage operations in preparing the field for planting the following spring. Fewer and less aggressive tillage operations preserve more of the trash cover reducing the potential for erosion. Tillage of light textured soils, where it is relatively easy to incorporate crop residues, should be delayed until spring. If fall tillage of a light-textured soil is carried out, it should result in no less than 65% of the ground covered with crop residue (Figure 3.4-10). The amount of residue buried by various tillage implements is shown in Table 3.4-4.

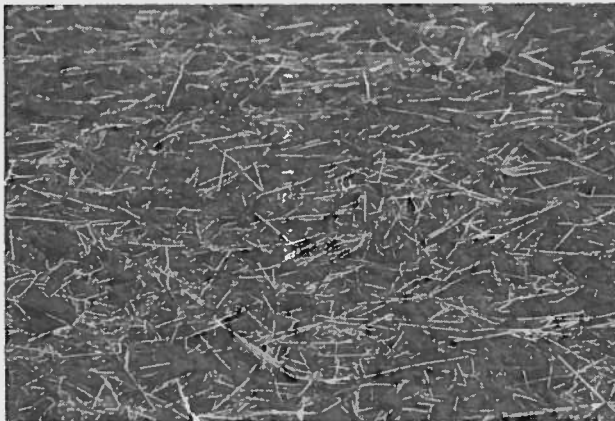
Table 3.4-4 Effect of different types of tillage implements on residue cover.

Implement	Straw Buried With Each Pass*
Field cultivator	10%-20%
Heavy duty cultivator	20%-30%
One-way disc	40%-50%
Heavy tandem or offset	35%-65%

* Residue reduction will vary depending on depth of operation, shovel type and speed of travel.

In Alberta, fall bedding and reservoir tillage are commonly used to prepare fields for planting to potatoes the following spring. The equipment used to form the beds preserves sufficient trash cover to limit erosion. Orienting the beds at right angles to the prevailing winds reduces the impact of wind on soil erosion. The construction of reservoirs between beds prevents soil loss from water erosion caused by snowmelt and heavy spring rains.

Figure 3.4-10 Field with 65% of the soil surface covered with cereal residue (Courtesy of Gaia Consulting Limited).



In the spring, a minimum amount of tillage should be used in preparing the soil so that trash cover is maintained. The producer should choose tillage methods that incorporate just enough crop residues to allow for trouble free planting, but preserve sufficient cover to prevent erosion.

Where practical plant potatoes rows at right angles to the prevailing winds to reduce drifting in the spring. In Alberta, rows may be oriented north/south as a method of frost protection. In the north/south orientation, both sides of the hill receive equal amounts of sunlight maximizing the solar radiation captured during the day.

Strip cropping (alternating strips of potatoes with a crop less prone to erosion) can be planted to reduce the unsheltered width in erosion-susceptible fields. Crop strips should be perpendicular to the prevailing winds in May. The width of strips will depend on the size of equipment used in cropping and the susceptibility of the soil to wind erosion. Recommended strip widths vary from 76 feet (25 metres) in loamy sands to 305 feet (100 metres) in silty clay loams.

Annual crops such as corn and sunflowers can be used as wind barriers to protect the soil after harvest. Properly spaced annual barriers also trap and evenly distribute snow for effective winter cover. Annual barriers should be planted closer together than tree shelterbelts because they offer less protection. The proper width and distance between annual barriers is shown in Table 3.4-5. Plant the barriers using the seeding rates that would normally be used for crop production.

Table 3.4-5 Recommendations for planting annual barriers.

Crop	Width		Barrier Spacing		Seeding Date
	metres	Feet	metres	feet	
Corn, Sunflower	1.5 - 3.5	(5 - 12)	18	(60)	normal seeding date

Harvest

In potato production areas where there are no stones, the potato harvester should be equipped with a vine shredder, which eliminates the need for tillage to anchor potato vines. Potato vines that are not anchored in the soil can blow off the field and accumulate in ditches, fences and shelterbelts. Shredding provides even distribution of chopped vine residue improving ground cover and reducing erosion potential (Figure 3.4-11). If the harvester is not equipped with a vine chopper, a tandem disc or a chisel cultivator equipped with coulters should be used to anchor, but not completely incorporate the vines.

Figure 3.4-11 Shredded potato vines after harvest (Courtesy of Gaia Consulting Limited).



Seeding an annual cereal after the potato harvest will provide good protection from wind erosion until a new crop is established the next season. The success of this method is dependant upon the harvest date and the growing conditions after harvest. The chances of establishing a cover crop after September 15th to 20th are poor. The fall cover crop can be seeded by air just prior to harvest or with a conventional seeder just after harvest. The emergence is less even when seeding by air. In Alberta, irrigation may be required to obtain even emergence of the cover crop. Some farmers choose to use wheat, oats or barley as a cover crop because the crop will winter kill and not interfere with future cropping plans. When choosing an annual cover crop, keep in mind that you will want a crop that germinates and establishes quickly. The malting varieties of barley are well suited to quick establishment. Many farmers will use a higher seeding rate to ensure a good ground cover in the

field, i.e. barley at 1.5 bu/acre (62 kg/ha). Others choose to seed fall rye or winter wheat as a cover crop. A non-selective herbicide is applied the next spring to control the rye or wheat, or the crop can be left to mature. Manure applied to the soil surface at 30-40 tons/ac (70-90 tonnes/ha) will reduce drifting. Researchers have demonstrated a link between high raw manure applications and an increase in the incidence of common scab, but this affect is rare. The nutrient content of the manure should be taken into account when planning commercial fertilizer applications the following season.

Seeding an annual cereal after the potato harvest will provide good protection from wind erosion until a new crop is established the next season.

Mulch can provide the same erosion control benefits as a well-established cover crop or well managed crop stubble. Broadcasting cereal straw with a round bale shredder onto the surface of erosion susceptible areas of the field will reduce wind erosion and add organic matter. The application of 1 to 3 tons/acre (2 to 6 tonnes/ha) will provide 65% ground cover, which is sufficient to prevent erosion.

Long-term Erosion Control Strategies

Fields susceptible to wind erosion can benefit from a systematic planting of shelterbelts. Trees should be planted perpendicular to the prevailing winds that occur in May. The prevailing winds at this time tend to have the highest velocity and fields have the least protective cover. A distance of approximately 660 feet (200 metres) between tree rows is recom-mended. The distance between green ash trees planted in the sheltebelt should be 6 to 8 feet (2.0 to 2.4 m) apart.

Fields susceptible to wind erosion can benefit from a systematic planting of shelterbelts. Trees should be planted perpendicular to the prevailing winds that occur in May.

In Alberta, there is a growing trend to reduce a soil's susceptibility to wind erosion through the build up of organic matter in the soil. The addition of composted manure on an annual basis at rates of 2.5 to 5.5 tons/ac (7

to 12 tonnes/ha) is a safe method of amending the organic matter and reducing the soil's susceptibility to erosion over time. Planting cereal and forage crops, which produce large amounts of organic matter, in rotation with potatoes helps reduce soil erosion. Care must be taken when including bean and canola crops in rotation with potatoes, as neither provides much crop residue.

For assistance with soil erosion problems, contact your provincial soil and conservation specialists or Prairie Farm Rehabilitation Administration (PFRA).

3.4.5 Fertility and Fertilizers (D. Waterer, J. Heard)

Potatoes managed for maximum productivity exert a heavy demand on soil fertility. Significant quantities of nutrients are removed from the field in the harvested tubers (Table 3.4-6), while additional nutrients are lost through erosion and leaching.

Table 3.4-6 Nutrient uptake by potatoes - lbs (kg) of nutrient for every ton of crop harvested

	Nitrogen	P2O5	K2O	S
Tubers	6.5 ¹ (5.7)	1.1 - 3.5 (1.0 - 3.0)	9.6 - 11.2 (8.5 - 9.9)	0.6 (7.6)
Vines	3.9 (3.5)	0.7 - 1.9 (0.6 - 1.7)	4.6 - 18.3 (4.1 - 16.2)	0.3 (0.26)
Total	10.4 (9.2)	1.8 - 5.4 (1.6 - 4.8)	14.2 - 29.5 (12.6 - 26.0)	0.9 (0.8)

¹ Range in nutrient removal reflects typical variations in tissue nutrient concentrations.

Nitrogen Nutrition and Management

Of all the essential nutrients, nitrogen most often limits potato production. Consequences and symptoms of nitrogen deficiency in the crop are:

- Stunted growth
- Premature death of vines
- Poor yields
- Increased susceptibility to diseases such as early blight and *Verticillium* wilt

Likewise there are consequences of excess nitrogen:

- Negative impact on environment - particularly due to nitrate leaching below the root zone
- Excessive vine growth, which can interfere with harvest
- Delayed tuber set leading to poor yields in regions with a limited growing season.
- More deformed tubers and hollow heart
- Tubers are physiologically immature at harvest, resulting in more harvest damage, poor storability and processing quality
- Low specific gravity

Attention should be paid to nitrogen management because of its influence on crop productivity, quality and the environment. Nitrogen management refers to placement methods, timing of applications and assessment of N status as well as N application rates.

Attention should be paid to nitrogen management because of its influence on crop productivity, quality and the environment.

Nitrogen placement and time of application

The relative efficiency of any nitrogen application varies depending on soil moisture, soil temperature, soil type, weed and crop growth. In Table 3.4.7 average efficiency of times and method of N application are compared to spring broadcast, which is given a value of 100.

Table 3.4-7 Average efficiency of times and method of N application

Time and method	Relative efficiency value
Spring broadcast	100
Spring banded	120
Fall broadcast	80
Fall banded	100

Efficiency values are based on nitrogen uptake by plants. Broadcast values assume urea-based nitrogen fertilizers are incorporated to minimize losses through volatilization of ammonia. This incorporation step is critical on soils with a high pH or which contain free lime near the surface, particularly when rainfall is not received following application.

Banding refers to applying fertilizer in-furrow or in bands below and to the side of the seed piece. Banding the N fertilizer restricts contact between the fertilizer and the soil. This delays nitrification of ammonia forms of N fertilizer, thereby reducing losses of nitrate-N. Banding also reduces loss of N due to contact with crop residues or immobilization.

Banding the N fertilizer restricts contact between the fertilizer and the soil, thereby reducing losses of nitrate-N.

Excessive rates of banded N can impair sprouting and reduce plant emergence. In-furrow applications of N while seeding, should not exceed 50 lbs N/ac (45 kg N/ha) in the urea form, while no more than 80 lbs N/ac (70 kg N/ha) nitrogen in urea form should be applied as a sideband application. Fertilizer bands established prior to seeding should not be disturbed prior to or during the seeding operation to optimise N efficiency.

Nitrogen losses due to leaching, denitrification, immobilization and weed growth are generally higher for fall-applied than for spring-applied N. These losses are further increased if the N is applied too early in the fall (prior to mid-September) or when soil temperature at the 4" (10 cm) depth is greater than 41°F (5°C). For these reasons, nitrogen should be applied in spring or in-season. In dry soil, banding N in late fall is as effective as spring banding.

Nitrogen losses due to leaching, denitrification, immobilization and weed growth are generally higher for fall-applied than for spring-applied N.

Nitrogen is relatively mobile in moist soil and therefore need not be applied near the plant to be effectively used. However, surface application or shallow incorporation can result in reduced uptake if the seedbed remains dry during the early growing season. Nitrogen applied in a band is more effective than surface applications when the soil is dry.

Split applications for nitrogen

Splitting the total N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching. Part of the crop's total N requirement is supplied prior to planting or is banded at planting. This initial application of N is supplemented with one or more applications of N. The first increment of N is usually applied after tuber initiation. Additional later applications may be used if a petiole nitrate analysis indicates a N deficiency.

Several methods are available for applying N after crop emergence.

- The most common method is top-dressing which involves broadcasting granular fertilizer over the growing crop. Ammonium nitrate is the preferred nitrogen source for top-dressing because it does not require incorporation after application. Urea can be top-dressed, but hilling or irrigation must be used to incorporate the fertilizer shortly after application. Liquid N can be dribbled onto the hill at the base of the plants, but it also must be incorporated after application. Care must be taken to avoid contact between the foliage and liquid N, as it will burn the leaves.
- Nitrogen fertilizers may be banded in the soil to the side of the emerged crop row. Delaying banding increases pruning of the roots and may reduce yields.
- Fertigation, which involves the injection of liquid fertilizer into the irrigation water, can be used to apply N and other nutrients throughout the growing season. Liquid urea-ammonium nitrate (28%) is the most common source of N injected into irrigation water. Uniformity of N application depends on the uniformity of water application from the irrigation system. Centre pivot and linear irrigation systems provide the most uniform application of water. Traveling guns and side-wheel roll systems do not distribute water as uniformly over the field as centre pivots or linear systems because of overlaps between moves. These systems should only be used to apply N fertilizer when the wind is very low and no other N application method is available.

Splitting the total N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching.

Nitrogen Assessment

Soil testing to a depth of 24 inches in the spring is critical to planning an effective and efficient N management program. Post harvest soil samples may help growers to select succeeding crops, which will make maximum use of the residual N after the potato crop.

Commercial soil test laboratories will provide N fertilizer recommendations based upon the nitrate soil test. The recommendations may vary with the soil type, the cultivar, end use of the crop, yield goal, the previous cropping and manuring history of the field. Each provincial soil specialist can also provide rate recommendations based on the soil test results.

Nitrogen management based solely on a soil nitrate test is challenging. In intensively cultivated and irrigated potato fields, mineralization of organic matter may add significant amounts of N. Even in relatively fertile soils, leaching or very high plant demand can cause in-season N deficiencies. The nitrogen demand by the crop during tuber bulking may be 2.5 to 3.5 lbs N/ac/day (2.2 to 3.0 kg N/ha/day). Petiole nitrate sampling allows for in-season monitoring of the crop's nutrient status. Collect the 4th petiole from 30 – 50 randomly selected plants throughout the field (Figure 3.4-12). Strip the leaflets from the petiole and keep the sample cool until shipping. Tissue samples are often collected weekly to track changes in nitrate levels, and to plan supplemental fertilizer applications should levels drop below optimum. Producers should follow laboratory instructions on tissue sampling techniques and interpretation of petiole nitrate results.

**Soil testing to a depth of 24 inches
in the spring is critical to planning
an effective and efficient N
management program. Petiole nitrate
sampling allows for in-season
monitoring of the crop's nutrient status.**

Critical petiole nitrate-levels decline as the potato crop develops and matures. Generally, petiole nitrate-N levels at tuber bulking are <10,000 ppm = low, 10,000-15,000 ppm = medium, >15,000 ppm = sufficient. (Figure 3.4-13)

Phosphorus

Soil Availability and Plant Uptake

Soil phosphorus (P) occurs in many forms depending on the pH and chemical composition of the soil. Only a small fraction of the total amount of P present in the soil is actually available to the crop within a given growing season, but the supply of available P is constantly replenished from soil reservoirs of less available P. Consequently, soil P levels are usually fairly stable over the course of the growing season and do not change much from year to year unless the field has been heavily fertilized. The roots absorb phosphorus ions dissolved in the soil water. Phosphorus deficiencies can occur even in soils with abundant available P if drought, low temperatures or disease interfere with the phosphorus diffusion to the root through the soil solution or otherwise impair development and function of the roots. Potato plants require an adequate supply of P throughout the growing season to achieve optimum yields. During the early growth stages, P stimulates the development of a vigorous root system and healthy tops. Plant demand for P peaks at tuber set and then slows during bulking as the nutrient needs of the developing tubers are met by translocating P from the tops of the plants.

Figure 3.4-12 Diagram showing 4th petiole (Courtesy of Agvise Laboratories)

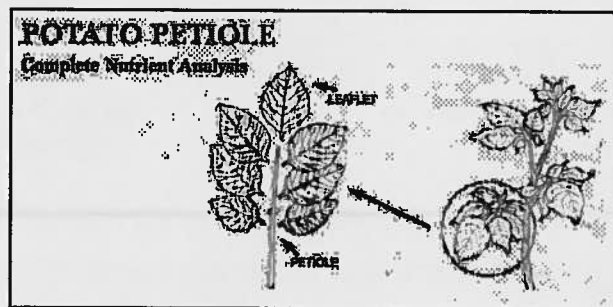
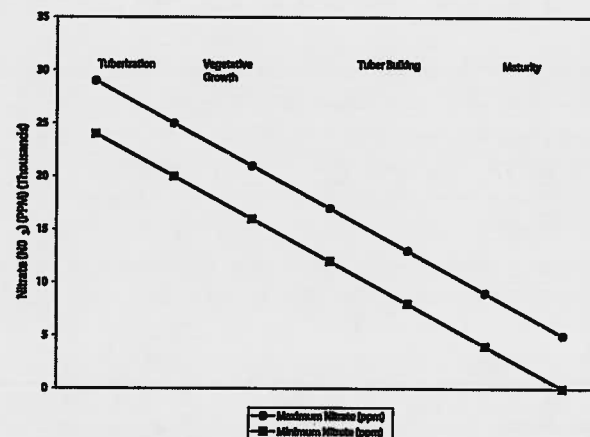


Figure 3.4-13 Target range for petiole nitrate in potato petioles



Phosphorus deficiencies slow growth and reduce yields without producing any obvious changes in the appearance of the crop. Only after P deficiencies have become severe will the crop begin to develop visible signs of P stress - stunted dark green leaves and the edges of the youngest leaves begin to fold downwards. As P deficiencies are difficult to diagnose based on the appearance of the crop, P status should be monitored by tissue testing. Optimum tissue P levels vary from 0.2-0.5%, depending on the crop growth stage (Table 3.4-8).

P Fertilizing Strategies

The P requirements of potatoes are much higher than the P levels typical of most Prairie soils and some type of P fertilizer program is usually required. Phosphorus application programs should be based on the recommendations obtained from fall or spring soil tests (Table 3.4-9). As P fertilizers are relatively expensive and the nutrient is immobile in the soil, the objective of the ideal P fertility program is to raise levels of available soil P in the effective root zone to precisely match the requirements of the crop. Band application of P fertilizer below and to the side of the seed row represents the most efficient means of meeting crop P needs with the minimum amount of P fertilizer. Placing the P fertilizer in a concentrated band adjacent to the developing root system increases the efficiency of fertilizer recovery by the roots

while also reducing fixation of the applied P into forms unavailable to the crop. Banding is particularly effective in soils testing low in P or with high P fixing capacity and in situations where growing conditions may interfere with development of a healthy root system. Broadcast/incorporating P fertilizers prior to planting represents a convenient option in soils requiring only limited P amendment.

Band application of P fertilizer below and to the side of the seed row represents the most efficient means of meeting crop P needs with the minimum amount of P fertilizer.

Although P is relatively immobile in soil, timely application of P as a sidedress treatment followed by irrigation or via fertigation with P may be useful if tissue tests indicate the crop is at risk of a P deficiency. This practice is only recommended when there is risk of a yield limiting nutrient deficiency and there are no other application options available. Excess application of P as either fertilizer or manure is economically and environmentally unsound but has little potential to reduce yield or quality.

Potassium

Soil Availability and Plant Uptake

Potassium (K) is supplied to the crop root through diffusion over short distances; hence K is also referred to as a relatively immobile nutrient in soils. Much of the K available to the plant is held on exchange sites on clay or organic matter, which replenishes the soil solution as root uptake of K occurs. Consequently, soil K levels are usually stable over the course of the growing season and from year to year.

Potatoes require abundant soil K, as this nutrient is crucial to metabolic functions such as the movement of sugars from the leaves to the tubers and the subsequent transformation of those sugars into starch. Potassium deficiencies reduce both the yields and quality of the potato crop. Potassium deficiencies impair the crop's resistance to diseases and its ability to tolerate stresses such as drought and frost. Tubers adequately supplied with K are more resistant to blackspot bruising or after cooking discoloration, while also experiencing less moisture loss and disease during storage. Potassium deficiencies typically first show up in the sandier or knoll areas of the field. As K is mobile within the plant, the lower leaves are first to display symptoms of K deficiency - yellowing of the leaves with scorching around the leaf margins. Severely deficient plants may take on a coppery sheen. Small dead

spots resembling the lesions produced by fungal disease may form on the leaves. As visible signs of K deficiency only become apparent once the crop is severely stressed, the K status should be monitored by tissue testing. Optimum tissue K levels vary from 2-5 %, depending on the crop growth stage (Table 3.4-8).

K Fertilizing Strategies

Potassium application programs should be based on the recommendations obtained from fall or spring soil tests (Table 3.4-9). As K fertilizers are relatively inexpensive, many growers opt to add a small amount of K fertilizer to potatoes even in K rich soils. Potassium fertilizer (20-40 lbs/ac [18-35 kg/ha]) applied in a band adjacent to the seed row may provide a jump-start to the emerging potato plants. To avoid salt damage to the crop, the total amount of all actual fertilizer nutrients applied as a band should not exceed 100 lbs /ac (88 lbs/ha). Broadcast/incorporating K fertilizers prior to planting represents the preferred approach in soils requiring more substantial K amendment.

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Although K is only moderately mobile in the soil, timely application of KNO₃ as a sidedress treatment followed by irrigation or via fertigation may be useful if tissue tests indicate the crop is at risk of a K deficiency. This practice is only recommended when there is risk of a yield limiting nutrient deficiency and there are no other application options available.

Muriate of potash (KCl 0-0-60) is the least expensive and most readily available form of K fertilizer. There is some evidence that excessive Cl associated with heavy application of KCl may reduce the specific gravity of the potato crop, but this is rarely an issue on the relatively K-rich Prairie soils.

Micronutrients

Although micronutrients (boron, chlorine, copper, iron, manganese molybdenum and zinc) are only required in relatively small quantities by the potato crop, they are no less important to the health and productivity of the crop than are the other nutrients. Although deficiencies of

micronutrients are relatively uncommon in Prairie soils, growers should still have the micronutrient levels in their soil evaluated prior to planting and should confirm the micronutrient status of their crop through tissue testing (Table 3.4-8). The micronutrient needs of the crop may be met through either soil or foliar applications. As micronutrients are relatively expensive and the margins between adequate and excessive supplies are often narrow, growers should exercise caution when utilizing these products. Check strips represent a useful tool for confirming the benefits and cost efficiency of any fertilizer treatment.

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Table 3.4-8 Recommended tissue concentrations of nutrients for potatoes. Check with your soil testing lab or provincial fertility specialist to obtain values appropriate for your production area, soil type, cultivar, management practices and anticipated end-use of the crop.

Nutrient	Recommended Tissue Concentration ¹
Phosphorus	0.2 - 0.5 %
Potassium	2.0 - 5.0 %
Calcium	0.4 - 4.0 %
Sulphur	0.2 - 0.5 %
Magnesium	0.2 - 0.5 %
Boron	15.0 - 40.0 ppm
Manganese	20.0 - 100.0 ppm
Copper	4.0 - 25.0 ppm
Iron	50.0 - 250.0 ppm
Zinc	20.0 - 70.0 ppm

¹ Critical tissue nutrient concentrations vary with growth stage, production

Table 3.4-9 General fertilizer recommendations for nitrogen, phosphorus and potassium for irrigated potatoes. Check with your soil testing lab or provincial fertility specialist to obtain values appropriate for your production area, soil type, cultivar, management practices and anticipated end-use of the crop.

Soil Nutrient Status	lb/acre soil N (0-24")	N fertilizer recommended (lb/acre) ¹	lb/acre soil P (0-6")	P ₂ O ₅ fertilizer recommended (lb/acre) ^{1,2}	lb/acre soil K (0-6")	K ₂ O fertilizer recommended (lb/acre) ¹
Low	0-35	130 - 200	0 - 25	90 - 70	0 - 120	240 - 190
Medium	35-55	150-160	25 - 50	70 - 40	120 - 250	190 - 110
High	55-75	120-150	50 - 90	40 - 10	250 - 370	110 - 30
Very High	>75	0-110	> 90	10	> 370	30 - 0

¹ Specific recommendations will vary depending on the site, soil type, cultivar, management practices and anticipated end-use of the crop.

² Recommendations for phosphorus fertilizer rates are based on band application. Recommended rates should be doubled if phosphorus fertilizers are broadcast.

3.5 Irrigation (D. Tomasiewicz M. Harland, B. Moons)

Reliance upon irrigation varies significantly across the Prairies Provinces. In Manitoba, northern Alberta and parts of Saskatchewan, irrigation is used to supplement precipitation. In Southern Alberta and parts of Saskatchewan, the majority of the moisture required to produce a marketable crop comes from irrigation. For potatoes, average seasonal irrigation amounts applied are 16 18" (41-43 cm) in southern Alberta, 10" (25 cm) in Saskatchewan, and only 3.5" (9 cm) in Manitoba. Regardless of the production area or amount of precipitation received, the practice of irrigation is similar. All irrigators strive to eliminate soil moisture deficits to produce a high yield of good quality potatoes. To determine when and how much to irrigate, irrigators must understand both soil-water and crop characteristics.

3.5.1 Soil Water Characteristics

Knowledge about the amount of soil water available to the plant and the ability to estimate soil water content is a key aspect in determining irrigation requirements of potatoes. An irrigator must understand the following terms to estimate soil water content.

Available soil water (ASW) is a common term of reference describing soil water content. Understanding the concept of ASW requires understanding of two additional terms related to soil water content.

Knowledge about the amount of soil water available to the plant and the ability to estimate soil water content is a key aspect in determining irrigation requirements of potatoes.

Field capacity refers to the amount of water a soil holds after water has drained out of the larger pores and moved out through the soil profile due to the force of gravity. In coarse textured soils it may take a few hours for a soil to move from a saturated status to field capacity, in medium textured soils this may take approximately 24 hours, while in fine textured soils this may take several days.

Permanent wilting point refers to the amount of water a soil holds when only water within the smallest of the pores and spaces around individual soil particles remains. This water is not considered available to plants since the energy required to extract it is too great for the plant roots.

Figure 3.5-1 Available soil water and soil texture.

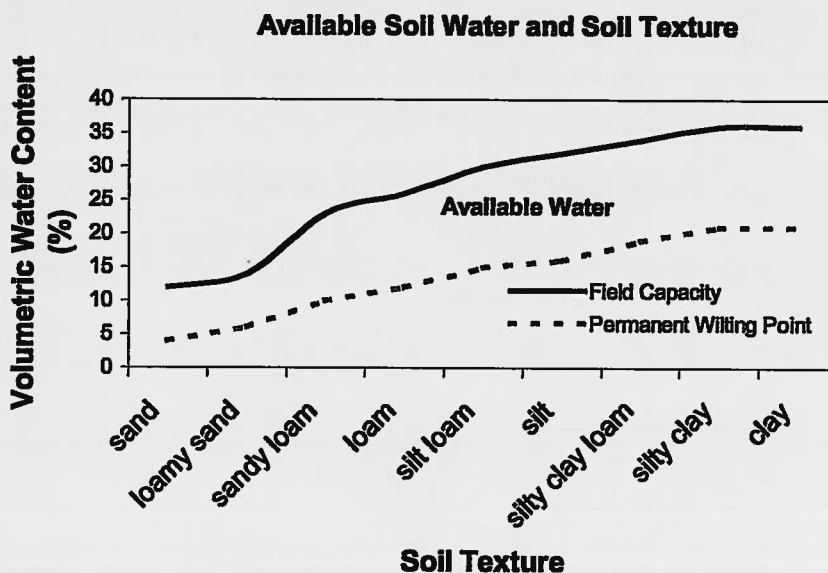


Table 3.5-1 Soil water contents for agricultural soils. Jensen, M.E., R.D. Burman, and R.G. Allen, 1990. *Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70. American Society of Civil Engineers, New York, NY.*

Soil Water Content on Volumetric Basis (%)								
Texture Class	Field Capacity		Permanent Wilting Point		Available Water		Water Holding Capacity (in/ft)	
	Average	Range	Average	Range	Average	Range	Average	Range
Sand	12	7-17	4	2-7	8	5-11	0.66	0.60-1.32
Loamy Sand	14	11-19	5	3-10	9	6-12	0.96	0.72-1.44
Sandy Loam	20	15-25	10	6-15	13	11-15	1.56	1.32-1.80
Loam	26	20-30	12	7-18	15	11-18	1.80	1.32-2.16
Silt Loam	30	22-36	15	8-21	16	11-19	1.80	1.32-2.28
Silt	32	23-36	15	12-18	17	12-20	2.04	1.44-2.40
Silty Clay Loam	34	30-37	19	17-24	15	12-18	1.80	1.44-2.16
Silty Clay	35	28-42	21	14-28	16	11-19	1.80	1.32-2.28
Clay	38	32-39	21	18-24	15	10-20	1.80	1.20-2.40

(Source: Jensen et al., 1990)

Any water held in the soil pores between the soil water contents of field capacity and permanent wilting point is considered available for extraction by plant roots for growth. The ASW capacity is the amount of water represented by the difference between field capacity and permanent wilting point. Soil texture is the main soil characteristic affecting ASW (Figure 3.5-1 and Table 3.5-1), however other factors such as structure, salinity, mineralogy and organic matter content also play a role.

3.5.2 Crop Characteristics

Potato is a moisture sensitive crop with a shallow active root zone compared to cereals and forages. Roots will penetrate to 3 feet (90 cm), however about 90% of the root activity takes place in the top 2 feet (60 cm) depth with a significant amount of that activity in the upper foot (30 cm). Availability of moisture in the root zone is crucial for high yields and is influenced by soil properties such as texture and percent organic matter. To maximize potato yield, maintain the soil moisture in the root zone above 65% of the ASW capacity.

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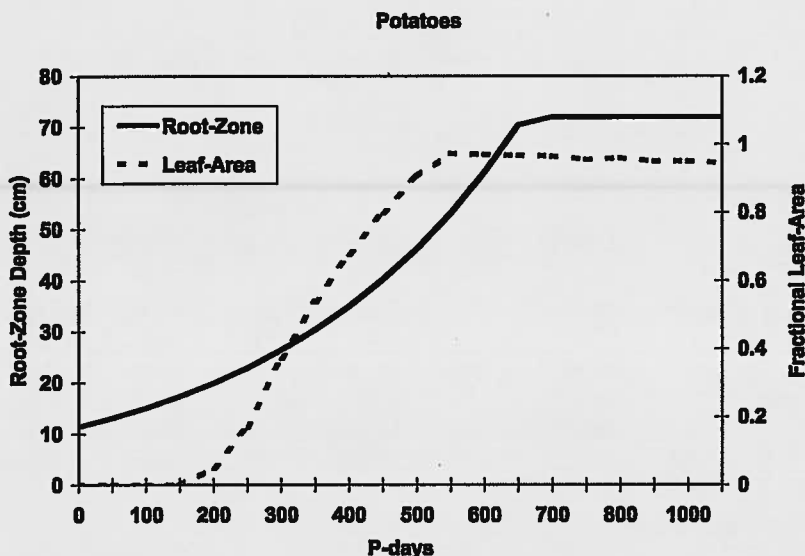
The optimum temperature for potato growth is 69°F (21°C). Severe growth restrictions occur when the temperature is below 45°F (7°C) or exceeds 86°F (30°C). This information is used to calculate heat units for potatoes, which are called P-Days. Figure 3.5-2

charts the rooting depth and growth stages of a Russet Burbank crop based on accumulation of P-Days. Root depth is important when estimating the amount of soil water available to the plant. A grower with access to P-Days for their production area can use the model in Figure 3.5-2 to estimate rooting depth and in turn the amount of soil water available to the potato plant. This use of root depth to determine ASW is discussed later in section 3.5.3 *Irrigation Management and Timing*.

The growth and development of potatoes can be broken down into five distinct stages, which are discussed in detail in Section 1.3 *Growth Stages*. The demand for moisture changes with each stage of growth as indicated in Table 3.5-2. Moisture demand increases as the crop begins to develop after emergence and peaks 7-9 weeks later during the tuber bulking stage of growth. Demand begins to decrease from the time of late bulking to maturation. To achieve maximum yield and quality, soil moisture should be maintained at or above 65% of ASW capacity for all stages of growth.

If soil moisture content is allowed to drop below 70% ASW during the tuber set/initiation, a reduction in tuber number per plant will occur. Water stress at any time during tuber bulking will reduce marketable yield. Low water levels or excessive fluctuation of water levels outside the desirable range can also reduce quality, contributing to growth deformities such as hollow heart, knobiness and growth cracks. Less water is required during maturation, but it is still important to ensure that there is sufficient moisture to maintain a healthy canopy to achieve high yields and specific gravity. Too much moisture during maturation can result in difficulties during harvest and increased storage rots.

Figure 3.5-2 Potato growth model for a Russet Burbank crop grown in Manitoba. (Courtesy of the Environment Canada, Winnipeg Climate Centre)



Growing a crop of potatoes requires 16–20 inches (400–500 millimetres) of water depending on weather and variety. This includes available soil moisture in the spring, which varies depending on soil type. Table 3.5-2 shows the rate of water use by potatoes at various stages of development and temperatures.

Note that at full canopy cover (7-8 weeks after emergence) and temperatures of 32°C, water use can be as high as 0.3 inches per day. Contact your provincial irrigation specialist to obtain a chart applicable to your production area.

Table 3.5-2 Daily potato crop water use as affected by maximum daily temperature and growth stage. (Courtesy of North Dakota State University)

Average potato water use (inches/day) (NDSU, 1988)															
Temp. °C	Weeks After Emergence														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
10-15	.02	.03	.04	.05	.07	.08	.08	.08	.08	.08	.08	.07	.06	.05	.04
16-20	.03	.04	.07	.09	.11	.13	.14	.14	.14	.13	.13	.12	.10	.09	.07
21-26	.04	.06	.09	.12	.15	.17	.19	.19	.19	.19	.18	.17	.14	.12	.10
27-31	.05	.08	.12	.16	.19	.22	.25	.25	.25	.24	.23	.21	.18	.16	.13
32-37	.06	.10	.14	.19	.24	.27	.30	.30	.30	.29	.29	.26	.23	.19	.16
Growth Stage	Vegetative			Tuber Set			Tuber Bulking						Maturation		

3.5.3 Irrigation Management and Timing

The goal of irrigation management is to maintain soil moisture level in the crop root zone in a range where crop yield and quality are not reduced due to either insufficient or excess moisture, while minimizing the risk of leaching of soil moisture and nutrients below the root zone. The risks of excess moisture and leaching are greater in Manitoba than in many other potato-growing areas, due to heavier growing season precipitation.

The goal of irrigation management is to maintain soil moisture level in the crop root zone in a range where crop yield and quality are not reduced due to either insufficient or excess moisture, while minimizing the risk of leaching of soil moisture and nutrients below the root zone.

Effective rooting depth (Figure 3.5-2) must be considered when assessing soil moisture available to the crop for irrigation scheduling purposes. A depth of two feet (60 cm) is often assumed for management of irrigation scheduling for potatoes; this would be applicable for most of the irrigation season. It is generally recommended that irrigation be scheduled to prevent root zone soil moisture from dropping below 65% ASW. That critical ASW for irrigation is somewhat higher for fine-textured soils than for sands, since moisture is held more tightly in finer soils at a given ASW.

The amount of water a soil can hold between field capacity (100% ASW) and 65% ASW varies from about one-third inch per foot of soil (2.8 cm per m) for very coarse soils, to about two-thirds inch per foot (5.6 cm per m) for loam to finer textured soils. The amount of irrigation water applied with each application should be set to not exceed this capacity of the soil to hold water within the desirable range. Otherwise, leaching through the root zone will occur. For example, if water is to be applied at 65% ASW, and a 24" (60cm) effective rooting zone is assumed, routine application of 1.25" (3.2 cm) of water per irrigation would be acceptable on a clay loam soil, but only up to about half that amount on a very coarse soil. Therefore applications should be smaller and more frequent on coarse soils. If soil texture varies considerably within the field, the maximum application amount should be based on the capacity of the coarsest textured soil that occurs over a substantial portion of the field.

3.5.4 Irrigation Scheduling Methods

Most irrigation scheduling methods are based on either information from direct determination of soil moisture in the field (feel method), or on soil water balance calculated from estimated crop water use (*checkbook* method), or on a combination of the two approaches.

Variability in soil characteristics across the field, as well as with depth will result in uneven soil moisture content and must be considered in design and use of any irrigation scheduling system. In addition to soil characteristics and soil water holding capacity, other factors will result in variations in moisture availability across the field. These include:

- Variability in crop vigour and growth
- Plant spacing
- Slope, which moves rain and irrigation water off of the field before it can infiltrate into the soil
- Hilling, which can also affect run-off and infiltration
- Non-uniformity of irrigation water application.

A balance must be struck between the costs of

under-irrigating the driest parts of the field and those of over-irrigating the wettest portions. Experience, which includes years of checking soil moisture levels throughout the field under various conditions, is invaluable. Scheduling based on actual soil moisture determination should ideally incorporate many sampling/monitoring points within each field. With fewer points used, the grower should scout more frequently to verify that those points are representative of most of the field. Scheduling based on water budgeting methods should always include some field scouting for verification. The amount of scouting required increases with moisture variability over the field.

Soil Moisture Determination using the "Feel and Appearance" Method

The most basic approach for determining the amount of soil water involves sampling of the soil in the root zone and estimating moisture content by the "feel and appearance" method (Table 3.5-3). Many soil samples representing the different soil types in the field must be collected to obtain an accurate estimate of moisture content. Though this method is laborious and requires experience to interpret the soil moisture content, it can be an effective way of estimating the ASW. Table 3.5-3 is a useful guide in determining soil moisture level.

Soil Moisture Determination using Instrumentation

A wide range of instruments is commercially available to measure soil moisture for irrigation scheduling. These include neutron probes, tensiometers and resistance blocks. Some indicate how tightly the water is held by the soil (i.e. moisture *tension*). Many indicate the amount of water in the soil (i.e. moisture *content*), usually by volume. For both, it is necessary to understand the relationship between soil water tension and content for the specific soil to interpret the results for best irrigation management (see section 3.5.1 *Soil Water Characteristics*). Most of the instruments are installed in the soil at the beginning of the irrigation season, eliminating the need to obtain soil samples. Some can even be equipped to transmit readings by telemetry.

Soil Moisture Determination using Soil Water Budgeting (Check Book Method)

Water balance methods of scheduling are based on calculated soil moisture levels through the growing season. All inputs and removals of water from the root-zone are measured or estimated frequently (usually daily), and a running "balance" of soil moisture is calculated.

At the start of the season, soil moisture level is either determined (e.g. by feel method), or assumed to be at

Table 3.5-3 Guide for estimating soil moisture by feel and appearance. (Courtesy of the USDA)

Soil Texture	Available Soil Moisture (% volumetric)				
	0-25	25-50	50-75	75-100	100 (field capacity)
Fine sand & loamy fine sand	Appears dry, will hold together if not disturbed, loose sand grains on fingers.	Slightly moist, forms a very weak ball with well-defined finger marks, light coating of loose and aggregated sand grains remain on fingers.	Moist, forms a weak ball with loose and aggregated sand grains on fingers, darkened color, light uneven water staining on fingers.	Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, heavy water staining on fingers, will not ribbon.	Wet, forms a weak ball, light to heavy soil/water coating on fingers, wet outline of soft ball remains on hand.
Sandy loam & fine sandy loam	Appears dry, forms a very weak ball, aggregated soil grains break away easily from ball.	Slightly moist, forms a weak ball with defined finger marks, darkened color, no water staining on fingers.	Moist, forms a ball with defined finger marks, very light soil/water staining on fingers, darkened color, will not slick.	Wet, forms a ball with wet outline left on hand, light to medium staining on fingers, makes a weak ribbon.	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers.
Sandy clay loam & loam	Appears dry, soil aggregations break away easily, no staining on fingers, clods crumble with applied pressure.	Slightly moist, forms a weak ball with rough surfaces, no water staining on fingers, few aggregated soil grains break away.	Moist, forms a ball, very light staining on fingers, darkened color, pliable, forms a weak ribbon.	Wet, forms a ball with well defined finger marks, light to heavy soil/water coating on fingers, ribbons between thumb and forefinger.	Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, thick soil/water coating on fingers.
Clay, clay loam & silty clay loam	Appears dry, soil aggregations separate easily, clods are hard to crumble with applied pressure.	Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied pressure.	Moist, forms a smooth ball with defined finger marks, light staining on fingers, ribbons between thumb and forefinger.	Wet, forms a ball, uneven medium to heavy soil/water coating on fingers, ribbons easily.	Wet, forms a soft ball, free water appears on soil after squeezing or shaking, thick soil/water coating on fingers, slick and sticky.

field capacity. Soil water inputs are rainfall (less estimated runoff) and irrigation. Soil water removals are evapotranspiration (ET) and deep drainage through the root zone, which is estimated from inputs and soil water holding capacity. Evapotranspiration is a combination of moisture loss from the soil surface by evaporation and from the plant tissue by transpiration.

The simplest approach is to estimate daily ET based only on crop age or stage of growth and daily maximum temperature. The ET values are derived from a chart similar to the one in Table 3.5-2, but with ET values applicable to your production region. More accuracy can be obtained using more frequently measured atmospheric condition, such as solar radiation, wind, temperature, and humidity. Other approaches use a device from which water evaporates under the local conditions (e.g. evaporation pan, atmometer). Daily ET is then calculated from the amount of water evaporated, by application of a factor for the crop stage.

A computer is usually used to do the daily calculations of soil water levels from the water input/output data. Irrigation is used to keep the soil moisture in the desired range. Since the checkbook method uses only an estimate of ET, and relies upon several assumptions about water behaviour in the soil, the actual soil moisture should be checked periodically and corrected. Under normal soil and weather conditions, checks are recommended every two weeks. For a more detailed explanation of the checkbook method, obtain a copy of the fact sheet *Irrigation Scheduling by the Checkbook Method* from the North Dakota State University Extension Service.

Irrigation scheduling is conducted through the growing season when there are other pressing demands on growers' time, such as pest management, crop nutrition, irrigation, and harvest of other crops. For this reason, and due to the specialized instruments or skill needed for some of the methods, many growers contract scheduling services or purchase related information - e.g. soil moisture monitoring, software, ET estimates.

3.6 Pest Management

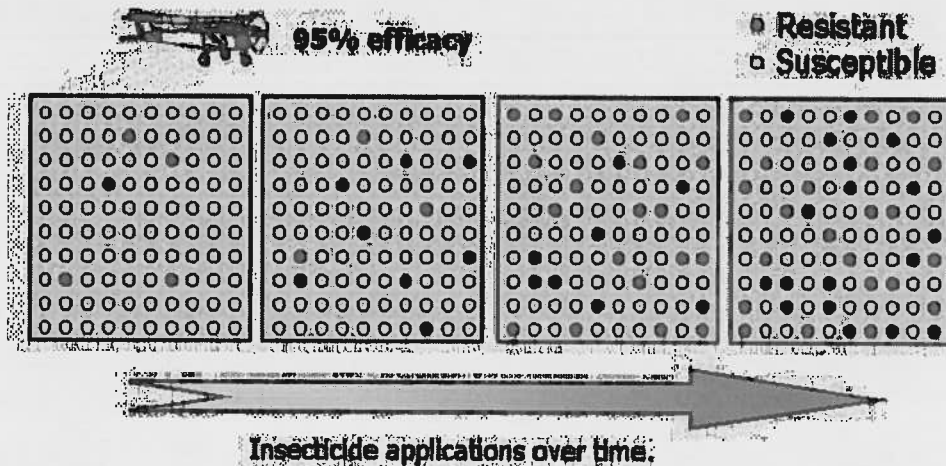
Apply only pesticides, which are registered for use in Canada and where there is a defined maximum residue limit (MRL) in the country of export. Countries, such as the United States, will not accept food with pesticide residues that are not approved by the Environmental Protection Agency. Consult with the potato processor or packer for a list of approved pesticides.

Apply only pesticides, which are registered for use in Canada and where there is a defined maximum residue limit (MRL) in the country of export.

3.6.1 Pesticide Resistance Management (Mark S. Goettel, Robert E. Blackshaw)

Selective breeding is an important tool in agriculture. Through selection of important traits, breeders have been able to produce the diversity of high yielding, high quality crops used in food production. Unfortunately, another form of selective breeding is detrimental. Through repeated application of pesticides, producers are inadvertently selecting resistant "breeds" of insects, weeds and diseases (Figure 3.6-1).

Figure 3.6-1 How Resistance Developments



All natural populations have a wide variety of genetic traits. Within a population, there may be a few individuals that are naturally resistant to a particular pesticide. Pesticide resistance develops when a pest population is constantly being selected through repeated use of pesticides with a similar mode of action. The few surviving individuals multiply and eventually replace the susceptible population. The rate of increase of the resistant individuals within the population depends on

the frequency of application and the reproductive potential of the pest in question.

Once resistance is established, pesticides within that chemical group are no longer effective. Weed resistance to herbicides is becoming more prevalent on the prairies and may affect weed management in potatoes. Populations of wild oats and green foxtail are known to be resistant to Group 1 herbicides (Poast Ultra, Select, Hoegrass 284). The Colorado potato beetle is notorious for its ability to have resistant populations selected, sometimes within two years after the introduction of a chemical with a new mode of action. Populations of the Colorado potato beetle in eastern Canada and most of the United States are resistant to many chemicals (Carbamates, Organophosphates, Organochlorines and Pyrethroids), forcing producers to rely on new chemical groups. Within the last several years, populations of the beetle resistant to most conventional insecticides have surfaced in Manitoba. To date, no insecticide resistance has been detected in Saskatchewan and Alberta.

The first signs of resistance are incomplete control of the pest after pesticide application. With weeds, this often appears as a healthy weed patch within a field where most weeds have been well controlled. However, before assuming resistance, other factors that could be responsible for pesticide failure must first be ruled out. Such factors include improper application (clogged

nozzles, drift etc.), unfavourable weather (rain following application, wind, drought, etc.), and emergence of new pests (egg hatches, weed germination, etc.). If you suspect resistance, then you are strongly encouraged to contact your provincial potato extension officer.

Managing to prevent resistance to pesticides.

Prevention is the key strategy in resistance management. Once resistance has established, there is no "cure". If available, alternative pesticides must be used. The development of pesticide resistance can be delayed by rotating between different groups (classes or families) of the pesticide, as each group tends to have a different mode of action. Pests or their offspring that survive an application would be killed by a pesticide from a different group in the following application. The rotation between pesticide groups could occur within the same or following season. Pesticide resistance management through rotation of pesticide groups is only possible in situations where totally resistant populations are not yet present. Adequate record keeping of pesticide use is critical when rotating pesticides over years to minimize resistance development.

Prevention is the key strategy in resistance management.

The development of pesticide resistance can be delayed by rotating between different groups (classes or families) of the pesticide.

Continued dependence on chemicals as the sole method of pest control is a sure recipe for the development of pesticide resistance.

Agronomic practices can play an important role in managing pests and the development of pesticide resistance. For instance, a cereal crop planted after potato harvest to protect soil from erosion may also aid in controlling weeds. Crop residues shade weeds that require light to germinate and physically impede growth of young seedlings. Additionally, rye is known to contain allel chemicals that inhibit weed germination and growth. To manage Colorado potato beetle, plant the potato crop at least 650 feet (200 m) from last year's crop. A significant number of beetles will over-winter in the previous field. The further the distance between the current potato crop and the source of over-wintering adults, the less chance the beetles will survive the journey to the new field. Refer to the sections on weed, insect and disease control below for more alternative pest control strategies that reduce dependence on chemical applications.

By implementing the following pesticide resistance management practices today, growers will ensure that there are more pesticides to choose from in the future.

1. Monitor your fields and apply pesticides only when necessary. Pest populations below an economic threshold can be beneficial, as they provide food for natural enemy populations and also serve to ensure genetic diversity within the

population (i.e. they interbreed with resistant individuals, thereby diluting the resistance trait).

2. Employ agronomic practices that play a role in managing pest populations. For example, maintaining at least 650 feet (200m) between the previous and present year's potato fields will reduce the survival of over-wintering Colorado potato beetle adults.
3. Apply pesticides only to areas of the field where the pest is a problem.
4. Alternate between different groups of pesticides. Remember to take into account the pesticides you may wish to apply to control other pests later in the season. For example, if you expect to use an insecticide to control aphids later in the season, then choose an insecticide from a different family to control Colorado potato beetles early in the season. Alternate pesticide groups within and between years. Refer to your provincial crop protection manual for a listing of the different chemical groups.
5. Never repeat a treatment because adequate control was not obtained. This is the first sign that resistance is high. Always change chemical groups if repeated treatments are necessary.
6. Contact your provincial potato crop specialist if you suspect resistance is present. The sooner resistance is detected; the earlier alternatives can be implemented.

For more information regarding pesticide resistance management and grouping of chemicals, consult your provincial crop protection guide.

Monitor your fields and apply pesticides only when necessary.

Pest populations below an economic threshold serve to ensure genetic diversity within the population (i.e. they interbreed with resistant individuals, thereby diluting the resistance trait).

3.6.2 Insect management (B. Elliott)

Chewing insects can cause serious yield and quality losses in potatoes by feeding on the leaves, stems or tubers. Sucking insects such as aphids and leafhoppers cause indirect losses by transmitting viral diseases.

Effective insect control depends on a combination of cultural and chemical practices. Good control of weeds and volunteer potatoes in and around potato fields removes alternative food sources for many of the pest

insects, particularly early in the spring before the crops have emerged from the ground. Field rotation will reduce the numbers of many pest insects, particularly Colorado potato beetles. Insecticides can reduce wireworm populations, however, regardless of an insecticide application, growers can expect reduced potato quality if they plant potatoes immediately following pasture or perennial grasses. Potato plants are more severely affected by insect pests when they are also suffering other stresses, so adequate moisture and fertility, as well as effective disease and weed management will minimize losses due to insects. Despite the effectiveness of cultural practices in reducing insect populations, insecticides are still required in most potato insect control programs.

Colorado Potato Beetle

Adult Colorado potato beetles are orange and black striped insects about 1/4" (0.6 cm) long (Plate 3). Adult beetles over-winter in the soil and in response to warmer temperatures in late May or early June they emerge and migrate by walking or flying to potato plants. Beetles cannot fly except when the temperature exceeds approximately 77°F (25°C) for several hours, so the majority of beetles walk to potato fields.

Once in the potato field, beetles feed; mate and the females lay orange eggs in groups of approximately 30 on the underside of potato leaflets (Plate 4). Eggs are laid over a period of several weeks in June, and usually hatch within 5 - 10 days. Because of the length of the egg laying period, some larvae may have completed development before others have hatched. Unless controlled, larvae are present in the field in late June and throughout July (Plate 5).

The young larvae are brick red with black spots; older larvae are orange with black spots. Larvae are slow moving, soft-bodied, hump-backed and feed on the leaves of the potato plant. Larvae are generally found near the top of the plant and they seldom move far from the plant on which they hatch, unless all the leaves are eaten. There are four larval stages, which differ mainly in size; newly hatched, first-stage larvae are about 1/10" (2.5 mm) long; fully-grown larvae of the fourth stage are about 2/5" (10-12 mm) long. From hatching to completion of the larval stage takes 2-3 weeks, and larvae feed almost continuously, except when moulting from one stage to the next. The third and fourth stage larvae (over 1/5" or 5-6 mm long) cause the most damage to the potato plant as they consume about seven times as much food as the previous two stages. In addition to the damage caused by feeding, the Colorado potato beetle is capable of transmitting spindle tuber virus and bacterial ring rot.

When the larvae have completed their development, they enter an inactive pupal stage in the soil. After 1 - 2 weeks, adults emerge from the pupae and begin to feed on the potato plants. Some years, the new adults may lay eggs that hatch into larvae in August or September. These larvae frequently die of starvation or cold, and do not contribute to future populations of Colorado potato beetles. Defoliation by larvae just before harvesting has negligible effect on yield. In late summer, the adults respond to senescence of potato foliage, shorter days and cooler temperatures by burrowing deep in, or close to, the potato fields in which they were feeding.

Using cultural control methods and augmenting them with insecticides only when necessary to prevent loss can reduce the development of insecticide resistance. The single most important cultural control method for Colorado potato beetle is field rotation where there is a 650 ft. (200m) separation between last season's and this season's potato fields. Colorado potato beetles usually over-winter close to last season's potato fields and are very vulnerable when they emerge in the spring if no food plants are close at hand. A 650 ft. (200m) separation between consecutive years' crops will reduce the survival rate of migrating adult Colorado potato beetles.

The single most important cultural control method for Colorado potato beetle is field rotation where there is a 650 ft. (200m) separation between last season's and this season's potato fields. Colorado potato beetles usually over-winter close to last season's potato fields and are very vulnerable when they emerge in the spring if no food plants are close at hand. Separation between consecutive years' crops will reduce the survival rate of migrating adult Colorado potato beetles.

Migrating Colorado potato beetles will often be concentrated at the edge of the potato crop. This phenomenon is called the edge effect. The edge effect occurs because under normal spring climactic conditions the adult beetles walk into new potato fields in the spring, and tend to stop after encountering the first plants. In this case, the density of females laying eggs, and of the resulting larvae, is much higher at the edge than in the middle of the field. There may be no Colorado potato beetles in the middle of extremely large fields. The pattern

of higher densities at the edge is less distinct when spring temperatures are abnormally warm, allowing adult beetles to fly into the field. The pattern may also change if the plants emerge unevenly. The first plants to emerge may attract more beetles.

The edge effect provides an opportunity to reduce the area where Colorado potato beetle densities are high and where insecticide application is required. The proportion of edge effect is reduced in larger relative to smaller fields. Increasing the size of field increases the proportion of the field where Colorado potato beetle densities are lower, and where insecticide treatments may not be required.

Insecticides should be applied only when they are justified economically; that is, when the cost of control is exceeded by the benefits of increased marketable yield. Applying insecticides when they are not economically justified reduces net return and promotes development of resistance. The level of insect population above which control is economically justified is called the economic threshold. Economic thresholds have been determined for Russet Burbank and Norland for the normal control situation in which spray applications are applied against larval populations in early summer.

The economic thresholds for Russet Burbank and Norland are quite low, because if the larvae are not controlled they will mature into adults that will also feed on the potato plants. Continuous defoliation throughout the season has a marked effect on yield. However, plants are quite tolerant of defoliation early in the season, so large numbers of larvae can be allowed to feed for a short time.

Insecticides should be applied only when they are justified economically; that is, when the cost of control is exceeded by the benefits of increased marketable yield.

The decision to make an insecticide application is not based entirely on the number of feeding larvae exceeding the economic threshold. The degree to which hatching is complete and the extent of defoliation must also be considered. Hatching takes place over a 5 - 10 day period, depending upon environmental conditions. The larvae are protected from an insecticide application while inside the egg. If a spray is applied during the early stages of hatching, the unhatched larvae will not be controlled and a second application may be required later in the season. Knowing that the plant is tolerant to defoliation early in the season allows for the insecticide application to be delayed until a greater portion of the larvae have hatched.

Larvae that have matured and are pupating in the soil will not be controlled by an insecticide application. If a spray is applied too late in the season while some larvae are pupating, a second application may be required when the pupating larvae emerge as adults.

The information contained in the box below shows how to calculate the economic threshold for Russet Burbank and Norland potato varieties.

Calculation of the economic threshold.

Calculate the economic threshold for each field or group of fields before sampling for Colorado potato beetle, using the following formula:

$$\text{Economic threshold} = \frac{(\text{Control Cost } \$/\text{ac or } \$/\text{ha}) \times 1800 \text{ (Russet Burbank) or } 600 \text{ (Norland)}}{\text{Expected Gross Revenue } (\$/\text{ac or } \$/\text{ha})}$$

Note: The same units must be used for Control Cost and Expected Gross Revenue.

The economic threshold is expressed in terms of the total number of large larvae (longer than 1/5" or 5 mm) and adults on a 20-plant sample.

Example: Control costs are \$15 per acre and the expected gross revenue is \$1500 per acre; economic threshold is 18 larvae per 20-plant sample.

Scouting for Colorado potato beetle larvae should begin 2 weeks after crop emerges. Twice weekly sample along field edges as this is where beetles will first appear, providing proper crop rotations are employed. Edge sampling consists of walking around the edge of the field and at corners and the midpoint of each side, counting the total number of the specified stages on 20 plants. Do not sample plants less than 1 yard (1 metre) from the field edge. Do not sample immediately neighbouring plants, skip a plant in between or move to the next row over. Record the number of beetles and perform the economic threshold calculation. Note also the percent defoliation. If the result of sampling indicates that the economic threshold has not been reached, repeat the sampling at the next scheduled interval. If the economic threshold has been exceeded and 10% or more of the foliage has been consumed, sample the field intensively to determine which parts of the field require treatment and apply insecticide immediately to areas where defoliation exceeds 10%. Sample again about 3 days after insecticide application (observe re-entry precautions on insecticide label) to determine whether application gave effective kill. If the insecticide was effective, sample intensively twice weekly until 6 weeks after plant emergence. If the total numbers of all larval stages and adults again exceed the economic threshold, apply the insecticide as soon as the largest larvae reach third stage more than 1/5" (5 mm).

Flea Beetles

Both the potato and tuber flea beetle species exist on the Prairies. Both types produce "shot holes" in the leaves (Figure 3.6-2), but only the tuber flea beetle causes tuber injury. The potato flea beetle sometimes reaches economic threshold levels in Manitoba, but it is not a problem pest in Saskatchewan and Alberta. The tuber flea beetle was first reported in Alberta in 1974, but has not yet become a significant pest. There is no evidence that it has expanded its range eastward.

Figure 3.6-2 "Shot holes" caused by a potato flea beetle



Potato flea beetle adults are black beetles about 1/10" (2 mm) long; their legs and antennae are brown (Plate 6). The beetles jump actively, particularly when disturbed, but they seldom, if ever, fly. The potato flea beetle overwinters as an adult among litter or undergrowth either in, or close to, the potato fields in which it fed the previous summer. In spring, the adults move to potatoes, where they feed on the foliage of newly emerged potato plants. If potatoes have not yet emerged, the adults feed on weeds or volunteer plants. In Manitoba, the spring adults are generally present in relatively small numbers. They feed on potato foliage making small round holes "shot holes" or scars in the leaf tissue. The eggs are laid in the soil. The larva, which is a slender white grub with a brown head and tiny legs, feeds on rootlets, and occasionally penetrates into developing potato tubers. When larvae are mature, they are about 1/5" (5 mm) in length. They moult into pupae, which are found in cells close to plant roots. Adults emerge from pupae and feed on potato foliage in late July and August. Populations of adults at this time may be high, and considerable "shot-holing" of potato foliage can result.

Potato flea beetle adults damage the potato plant by defoliation "shot holes", which can cause yield loss.

Direct damage from potato flea beetle is mainly attributable to defoliation "shot holes" of plants during late summer. Occasionally, larval feeding may cause tubers to be pimply or to have short tunnels bored into the tuber to a depth of 1/10" (3 mm) or less. Most of this injury can be removed by peeling. Fungal diseases, such as Verticillium wilt, Fusarium dry rot, rhizoctonia and common scab have been reported to be associated with potato flea beetles. Transmission of bacterial diseases and spindle tuber viroid may also occur.

Cultural control measures for potato flea beetles include crop rotation, field rotation where there is a separation of this year's potato fields from last year's potato crops and control of weeds in the nightshade family. It has been noted that beetles are more abundant where potato crops are adjacent to uncultivated areas.

Insecticides should be applied to the late summer generation of flea beetle adults if feeding damage is severe. Early maturing potato varieties are more susceptible to feeding damage than late maturing varieties. Emergence of flea beetles from pupation occurs over several weeks, so applications should be delayed as long as possible after the beginning of emergence, as insects in the soil will be unaffected by the

insecticide. At the time of this application, Colorado potato beetle adults may also be on the plants, so it is important that the insecticide used to control flea beetles not be from the same group that was used to control of Colorado potato beetle larvae earlier in the season.

Late summer populations of potato flea beetles below 65 per plant for Norland and 300 per plant for Russet Burbank do not cause economic yield loss in unstressed potato plants. However, plants, which have previously experienced defoliation from other insects are very sensitive to potato flea beetle injury, and may suffer economic loss with late summer populations of as few as 22 flea beetles per Russet Burbank plant. Economic injury can also be estimated by assessing the percent defoliation. Early in the season, healthy plants can withstand 10% defoliation (regardless of the insect causing defoliation) without an economic loss. Later in the season (August), healthy potato plants can withstand up to 25% defoliation without suffering a serious yield loss.

Aphids

Aphids are small, soft-bodied insects that originate mostly from local populations, but some arise as migrants blowing in from the United States (Plates 7 & 8). After appearing in fields in mid-June to early July the population can increase rapidly to peak in the second or third week of August then decrease by early September. Although aphids are normally wingless, winged forms may appear when environmental conditions in the field deteriorate or as a response to overpopulation.

Aphids transmit viruses and in rare circumstances reduce marketable yield. Identification and control of aphids is important in potato seed production, where the tolerance for total virus levels is extremely low (Table 6.5-1). Aphids control is less important in processing and table production where only the potato leaf roll virus (PLRV) causes an economic loss (Plates 26 and 27). PLRV, which is transmitted by the green peach aphid, causes net necrosis in the tuber and reduces market quality. In rare circumstances, high populations of feeding aphids will remove enough plant sap to damage the crop and reduce yield. The plant damage resulting from feeding aphids occurs in small-localized areas of the field referred to as "aphid holes".

Potato Aphids (PA)

The potato aphid is the largest and most numerous of the aphid species found in potato fields. Potato aphids are up to 1/10th of an inch (3.5 mm) long, and are usually green; however individuals may be red, brown, yellow, orange, or even purple. The body of the potato aphid is

elongate and pointed at the hind end. These aphids are found on the underside of potato leaves. Potato aphids over-winter on the Canadian Prairies in the egg stage on rose bushes. Wingless females hatch from these and produce live young females, some of which develop wings and fly to new hosts. There are several generations of winged and wingless forms during the summer. Winged males and females fly to rose bushes during late summer and early fall where the females give birth to wingless females that mate with the winged males and produce the winter eggs.

Aphids are small, hard bodied insects that transmit viruses and in rare circumstances reduce marketable yield.

Potato aphids are efficient vectors of mild and rugose mosaic (PVY) viruses. The potato aphid is a poor vector of potato leaf roll virus when compared to the green peach aphid (discussed below). In spite of being a poor vector of PLRV, extremely high populations of potato aphids may be as much of a factor in PLRV transmission as a small population of green peach aphids. In addition to virus spread, a toxin produced by the potato aphid is injected during the feeding process and may cause mottling, curling or premature death of the leaflets. Large quantities of honeydew excreted by the insects may cause the tops of the plants to become sticky if populations are extreme.

Green Peach Aphids (GPA)

Green peach aphids are smaller than the potato aphid (not more than 1/8" or 2.3 mm long), and the body is egg-shaped and lacks a pointed hind end. GPA varies in colour from creamy white to peach and even pinkish, but is most often pale green. In the green peach aphid, the antennal tubercles are prominent and inward pointing (appearing like a bottle cap opener). The GPA does not over winter outdoors in Manitoba. Populations may be maintained from year-to-year by over wintering in greenhouses, but it is likely that many populations migrate from the southern United States. In the spring, winged females are carried outside with bedding plants and then fly to weeds. They multiply rapidly for several weeks and by July they move to potatoes and fly from field to field, transmitting viruses to healthy plants. Winged females usually appear in the fall and some of these are successful in becoming established in greenhouses or root cellars.

Green peach aphids are highly efficient vectors of the potato leaf roll and rugose mosaic (PVY) viruses. Like potato aphids, they inject a toxin during the feeding, which causes leaf deformities, streaking, and even leaflet death.

Buckthorn Aphid (BA)

The buckthorn aphid is smaller than the potato aphid (1/16-1/8" or 1.2 - 2.0 mm) and the same shape as the green peach aphid. They are relatively easy to tell apart based on the antennal tubercles, which are small and hardly noticeable in the buckthorn aphid. In the green peach aphid, the antennal tubercles are prominent and inward pointing (appearing like a bottle cap opener). BA over-winter as eggs on buckthorn plants. In the spring, the eggs hatch and the larvae move from host plant to weeds, and by mid-July to potato plants. Late in the summer, the winged males and females give birth to wingless forms that mate and lay eggs for over-wintering. Summer populations are usually localized but, in those fields, this may be the most abundant species of aphid and, in a dry year, it can spread throughout the field. Buckthorn aphids are not as efficient at vectoring PLRV, but are a very effective vector of PVY.

Scouting and Control of Aphids

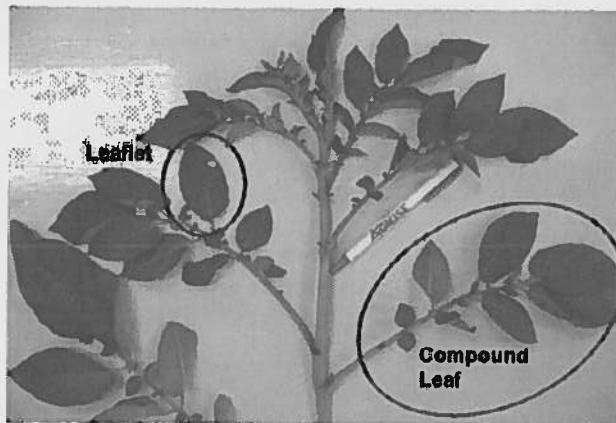
Seed potato growers must control problem populations of aphids early to maintain seed quality. The amount of potato leaf roll virus (PLRV) that spreads in a field is influenced by the population of aphid vectors in the field, the incidence of PLRV in the aphid vector and the incidence of PLRV in the field. To determine the potential for leaf roll virus spread, aphids must be identified and counted starting in early July when aphids begin to occur in potato fields. Divide fields into four plots, 25 leaves are taken from each of the four plots, and potato aphids and green peach aphids are counted on each compound leaf sampled (figure 3.6-3). A ten-powered magnifying lens is required to identify young aphids. The large body size and elongated shape of the potato aphid distinguish it from the smaller oval-bodied green peach aphid. Green peach aphids are typically found on the lower 1/3 of the canopy, nearer the ground. BA and PA are typically found in the upper 2/3 of the canopy. It should be noted that depending on how quickly the aphids are located after colonizing a plant, green peach aphids might still be found in the upper 2/3 of the canopy if insufficient time has passed for it to move to the lower canopy.

Seed potato growers must control problem populations of aphids early to maintain seed quality.

The number of aphids detected in a count is totalled and compared with the economic threshold for that field. Thresholds for green peach aphid are based on sampling 100 lower leaves (25 lower leaves in each of 4 areas of a field). The economic threshold is 3-10 aphids per 100 lower compound leaves for seed and 30-100 aphids per 100 lower leaves for processing. There currently are no established economic thresholds for buckthorn and potato aphids.

In order to accurately identify aphid species, consult with an agrologist. Check with your provincial specialist for recommendations on which registered products are most effective for controlling aphid populations. Repeated applications of other insecticides may select for resistance very rapidly, and the second and subsequent uses of the compound may not be effective.

Figure 3.6-3 Compound Leaf (Courtesy of Agvise Laboratories)



Leafhoppers

The potato and the six-spotted leafhopper species occur in Western Canadian potato fields. The most abundant species is the potato leafhopper, which feeds and reproduces on potatoes. The adult potato leafhopper is an active, narrow-bodied, pale green insect about 1/10th of an inch (3 mm) in length. The wings are pointed and somewhat longer than the body (Plate 9). Potato leafhopper nymphs are found on the underside of potato leaves (Plate 10). They are small, wingless versions of the adult, neon green in colour, and move very quickly in a crab-like motion. Potato leafhoppers do not over winter in Western Canada, but migrate from the southern United States in mid-June. This generation gives rise to a second, larger generation in August. The potato leafhopper injects a toxin into the plant, which results in hopper burn, a yellowing and curling of the tips and margins of the leaflets, which ultimately turn brown and brittle. The damaged plants die prematurely and the yield may be reduced.

The potato leafhopper injects a toxin into the plant, which results in hopper burn, a yellowing and curling of the tips and margins of the leaflets, which ultimately turn brown and brittle. The damaged plants die prematurely and the yield may be reduced.

Economic thresholds are determined by counting the wingless nymphs on compound leaves taken from mid canopy. Sample 100-175 plants from three to five areas of the field. Calculate the average number of nymphs per 10 compound leaves (Figure 3.6-3). The action threshold, at which an insecticide application is needed to prevent hopper burn and yield loss, is 1 nymph per 10 leaves. In years with abundant leafhoppers, this threshold may be exceeded twice, once in the first generation and once in the second generation. However, in many years the threshold is never reached.

The six-spotted leafhopper is normally much less abundant than the potato leafhopper. This species does not reproduce on potatoes, so only winged adult forms will be detected on potato plants. The adult six-spotted leafhopper is a tapered, pale grey-green insect, which flies actively. The insect is about 1/10th of an inch (3 mm) long and the head is marked with paired dark spots. Six-spotted leafhopper eggs over-winter on fall-sown cereals and grasses and hatch in May into tiny, black, wingless nymphs. These reach maturity in about three weeks, and as cereals and grasses mature in early summer, adult six-spotted leafhoppers disperse to other plant species, including potatoes. In addition to this resident population, adults migrate in large numbers from the southern United States.

This leafhopper does little direct damage to potatoes but spreads the pathogen causing aster yellows or purple-top wilt disease. The sucking adults feed on infected plants and then spread the disease to healthy potatoes. This disease is not of economic importance on the Canadian Prairies.

Weed control is the major cultural control method for the six-spotted leafhopper. Weeds provide a place for the insects to breed and are source of the pathogen that causes purple top wilt. Where six-spotted leafhopper populations are large, and especially if purple-top wilt or aster yellows has been found in a grower's field or on neighbouring farms, insecticide control measures must be taken.

Wireworms

Several species of wireworms infest Western Canadian potato fields. Wireworms are the larvae (Plate 11) of slender black beetles known as click beetles. The larvae are elongate-segmented insects that are glossy brown or brownish-white and are usually slightly darker at each end. Adult click beetles emerge in the spring from the soil where they wintered. Shortly after mating, the female beetles lay up to 300 eggs in the soil, usually around grass roots. Eggs hatch within a few weeks, and the larvae begin feeding on root hairs and fungi. At this stage, they are usually overlooked as they are small and the injury

they cause is negligible. Larvae go through about ten moults over a period of several years before pupating. With increasing size, their feeding habits change. After two moults, larvae can feed on most underground parts of newly germinating plants. Later stages are increasingly voracious and injurious to roots, seeds and underground storage organs such as potatoes. It is the later larval stages that cause the greatest damage to potatoes. Wireworms may reach 1.2 inches (3 cm) in length and, although they have flexible bodies, they are relatively tough and resistant to crushing. They have three pairs of short legs close to the front end. The rear segment is flattened and either comes to a point or has paired hooks separated by a central gap.

The adults do not attack potatoes, however the larvae feed on potato seed pieces and daughter tubers. Wireworm damage to seed pieces provides an entry point for blackleg and *Rhizoctonia* disease organisms. The greatest damage occurs when larvae tunnel into processing or table daughter tubers, rendering them unmarketable.

Wireworms thrive in grassland, so the most severe damage occurs following pasture. Of the field crops grown on the Canadian Prairies, wireworms prefer cereals. Continuous cropping with cereals favours increased wireworm populations. Non-cereal crops, such as weed-free alfalfa, impair the survival of newly hatched larvae, however, once larvae have completed one season of development they are tolerant of starvation and may be able to survive up to 2 years without a suitable food crop. For this reason, rotation by itself is seldom an effective control measure.

Since transportation in soil on machinery is of the main ways in which many species of wireworms move to new areas, precautions should be taken to prevent this. For example, areas in a field with known infestations can be cultivated or harvested last, and the implements thoroughly cleaned after.

Although wireworms tend to remain in the same area of a field throughout their larval development, they move vertically in the soil to find food, and in response to soil moisture and temperature. Wireworms searching for food detect carbon dioxide and home in on its source. This characteristic can be used to detect wireworms by using baits that give off carbon dioxide. Baiting provides a poor estimate of wireworm density in a field, but it is a quick way of determining whether the pest is present. A mixture of grain corn and wheat should be moistened to start germination and placed into a nylon mesh bag and buried 4 to 6 inches (10-15 cm) into the soil and marked with a flag. Several baits should be buried randomly over the field. Every two weeks, the baits should be excavated and inspected for the presence of larvae.

Continue baiting until wireworm activity is detected or until early September when larvae activity ceases. Baits do not work in soil that is either excessively wet or too dry.

Baits will enable growers to delineate areas of a field where wireworms are present, which may augment evidence of their presence from previous tuber damage. Because of the long lifespan of wireworms, damage may continue in the same field for several years, although severity will depend on weather and crop rotation. At the time of publication, Thimet is the only insecticide registered for control of wireworm. This product will no longer be available after 2004. Alternative fields should be considered if populations of wireworms are high.

Wireworm larvae cause the greatest damage by tunnelling into processing or table daughter tubers, rendering them unmarketable.

Variegated cutworm

Variegated cutworm caterpillars occasionally infest potato fields late in the season. This caterpillar is about 1.5-2" (40 to 50 mm) long when mature and grey to dull brown with black stripes along the side. It also has a row of yellow to orange spots along the top line and a prominent black "W" on top of the last body segment. Adults are brown miller moths. Larvae feed on the plants above ground, causing defoliation, but are found in the soil during the day. Field inspection for this pest is best accomplished in the morning. They feed readily on foliage but do not damage the tubers. As with other defoliating pests (CPB, flea beetles), late season potato crops can withstand up to 25% defoliation without suffering yield losses.

3.6.3 Weed management (B. Geisel)

Weeds compete directly with the potato plant for light, water and nutrients. Dense weed infestations restrict growth resulting in smaller tubers, lower dry matter content and poor quality. In addition to reducing yield and quality, weeds:

- Interfere with the harvesting operation.
- Interfere with in-field seed inspections
- Interfere with roguing of seed fields
- Restrict air flow through the canopy, which increases the potential for disease development
- Provide alternate hosts for diseases and the insects capable of spreading disease.

Competition between potatoes and weeds should be minimized from planting to the time of canopy closure;

6 to 7 weeks later. Weeds that emerge after row closure usually will not compete with the potato crop so long as the canopy is uniform and dense. Crop uniformity and density is determined by the stature of the variety and the uniformity of plant spacing. Plant misses as a result of poor quality seed, planting into cold soil or a malfunctioning planter will reduce crop density and competitiveness with weeds. It is important that the planter be operating efficiently not only to produce a high yield, but also to produce a uniform competitive plant stand. See *Planter Operation* in section 3.3.3 *Planting for Better Stand, Yield and Quality*.

Competition between potatoes and weeds should be minimized from planting to the time of canopy closure; 6 to 7 weeks later. Weeds that emerge after row closure usually will not compete with the potato crop so long as the canopy is uniform and dense.

A potato grower's weed control strategy should be an integrated approach consisting of cultural, mechanical and chemical methods to control weeds.

Cultural methods include field selection, management of weeds in crop rotation and preventing the entry of new weeds into a field. Growers should be familiar with weed problems from previous crops because this information is essential for field selection. It is important to select a field free from weed problems, which cannot be controlled by tillage and herbicides used in the production of potatoes. Potato growers should attempt to control perennial weeds such as Canada thistle and quack grass, in other crops in the rotation because there are few herbicides registered for use on potatoes that are effective against these weeds. It is also important to prevent the entry of new weeds into the field via equipment, livestock and manure. Ideally, escape weeds should not be allowed to set seed.

A combination of the following chemical and mechanical weed control methods is used to control weeds in the potato crop: (Figure 3.6-4):

- Herbicides (pre-plant incorporated, pre-emergence, pre-emergence burn-off and post-emergence). Consult with your *Provincial Guide to Crop Protection* for information about pesticides registered for application on potatoes.
- Mechanical (harrowing, cultivation and hilling)

Figure 3.6-4 Timing of Weed Control Operations Based on Number of Weeks Before and After Planting.

	Weeks Before and After Planting								
	-1	0	1	2	3	4	5	6	7
	Planting			Emergence			Row Closure		
Pre-Plant Herbicide	←→								
Pre-Emergence Herbicide			←→						
Harrow			←→	←→	←→	←→			
Cultivate			←→	←→	←→	←→	←→		
Hilling			←→	←→	←→	←→	←→		
Pre-Emergence Burn-off				←→					
Post-Emergence Herbicide						←→	←→	←→	←→

Herbicide Weed Control

Pre-plant incorporated herbicides are effective in controlling a broad spectrum of annual weeds early in the season. Incorporation of pre-plant herbicides dries and compacts the soil and buries crop residue, leaving it susceptible to wind erosion. Soil-applied herbicide should only be used in areas that receive adequate rainfall or where irrigation is available to activate the herbicide. Cultivation and hilling will disturb the herbicide treated soil allowing weeds to germinate, so apply pre-emergence herbicides after hilling.

Potatoes emerge approximately 15 to 30 days after planting. In that time, a significant number of weeds can germinate. An application of a non-selective herbicide just prior to emergence of potatoes will control annual weeds and set back perennial weeds. Burn-off herbicides are not affected by tillage operations. If hilling is performed just prior to emergence of potatoes than a pre-emergent herbicide may not be required.

Post-emergent herbicides are most effective when applied to weeds just after emergence and through the cotyledon stage of growth.

Herbigation can be used to apply herbicides in Western Canada. Herbigation is the process of applying an herbicide to the soil or plant surface by injecting the chemical into the irrigation water. Some herbicides are more effective if applied with irrigation water. This is especially true for pre-emergence herbicides that require moisture to be activated. Not all herbicides that are registered for use on potatoes can be applied through herbigation. Consult the chemical manufacturer or your local agricultural representative before herbigrating.

It is important that a pre-emergence herbicide be in the top 3 inches (7.5 cm) of soil, when applied by herbigation. The amount of irrigation water required to incorporate the herbicide will depend upon the water holding capacity of

the soil, soil moisture status at the time of herbigation and the desired incorporation depth. To ensure uniform chemical distribution, use only centre pivot or linear irrigation systems and apply when wind velocities are less than 10 mph (16 kph). Herbigation should not be carried out without having the proper anti-pollution systems in place to prevent pesticides from entering the water source. Refer to the following publications for information about anti-pollution safety devices on an herbigation system: Alberta Agriculture's *Chemigation Injection in Irrigation Systems* Agdex 753-2, Oregon State University's *Chemigation in the Pacific Northwest* PNW 360 or the University of Nebraska's *Anti-Pollution Protection when Applying Chemicals with Irrigation Systems* EC 89-730-B.

Always consult the current edition of your *Provincial Guide to Crop Protection* for detailed information concerning herbicides registered for potatoes, varietal restrictions, application rates, pre-harvest intervals and weeds controlled. Growers should use this reference as a guide and always read the herbicide label for specific instructions.

Mechanical Weed Control

Tillage is an effective tool for controlling annual weeds, however, if performed under the wrong conditions it can have a deleterious effect on the efficiency of harvesting operations, yield and quality. Tillage performed at any stage of growth will dry and compact the soil. Tillage performed when the plants are greater than 6 inches (15 cm) in height will prune roots and damage foliage. These effects can result in more than a 5% loss in yield. Tillage performed under wet conditions, will produce soil clods that will reduce harvesting efficiency and increase the incidence of blackspot bruising. For these reasons, potato growers should rely on herbicides for weed control and perform as few tillage operations as possible. Of the available tillage operations, only hilling is required in the production of potatoes. It is becoming more common for potato growers to perform only a single cultivation-hilling operation just prior to or shortly after emergence.

Tillage is an effective tool for controlling annual weeds, however, if performed under the wrong conditions it can have a deleterious effect on the efficiency of harvesting operations, yield and quality. For these reasons, potato growers should rely on herbicides for weed control and perform as few tillage operations as possible.

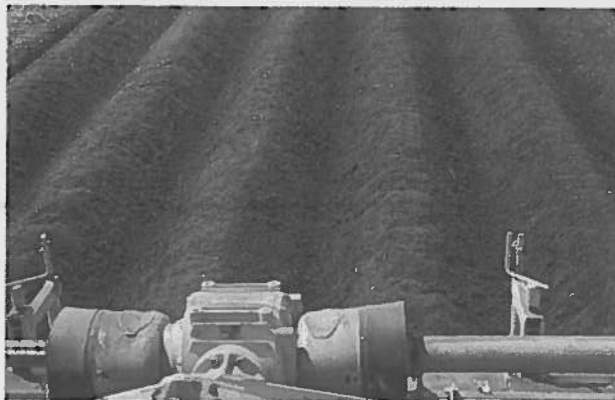
Mechanical tillage operations harrowing, cultivation and hilling operations can be performed before and after emergence; separately or combined (Figure 3.6-4):

Harrowing is performed with spring tooth harrows and if carried out when the weeds are just emerging, it can be an effective method of controlling weeds in the planted row. Harrowing can be performed separately or in combination with cultivation. Harrows should not be used after the plants are 2 inches (5.0 cm) in height, due to excessive damage to the roots, stolons and foliage.

Inter-row cultivation is performed with an S-tine shank cultivator or a rotary hoe and is most effective in controlling annual weeds between the rows. The cultivator can be adjusted to throw soil around the base of the plants, which will bury weed seedlings or it can be equipped with a spring tooth harrow to control weeds in the planted row. The S-tine cultivator is also used to loosen soil, which aids in the hilling operation. Inter-row cultivation should be carried out before the plants are 8 inches (20 cm) in height to avoid excessive root pruning.

Hilling is the only tillage operation necessary in the production of potatoes. The objective of hilling is to cover the daughter tubers with sufficient soil to prevent greening, minimize infection with late blight, minimize frost damage, improve drainage in the area of tuber formation and to facilitate harvest. Rotary hoes, discs, mouldboards, or power hillers equipped with a metal mould are commonly used to shape loose soil into a hill. The hilling implement should be adjusted to produce a wide, flattened hill ideal for protecting the tubers from sunlight, late blight spores and frost (figure 3.6-5). To effectively control weeds, hilling must take place before the weeds get past the two true leaf stage. Hilling can be performed pre or post emergence. Regardless of the hilling implement used, emerged plants should not be covered with soil. This sets the plants back and delays growth. It is recommended that power hilling be carried out prior to emergence to avoid covering the plants. Post-emergent hilling, other than power hilling, should be completed before the plants are 8 inches (20 cm) in height to avoid damage to the roots and foliage.

Figure 3.6-5 Ideal profile of a potato hill (Courtesy of Gaia Consulting Limited)



3.6.4 Disease Management (Tracy Shinnars-Carnelley, Piara Bains, Debbie McLaren, Jill Thomson)

Potato plants are susceptible to a wide variety of diseases that can severely reduce yield, quality and storability of tubers. Diseases can occur in the field or in storage and are caused by infectious bacteria, fungi, viruses and other related organisms.

Most infectious potato diseases can be controlled using certified seed, proper sanitary practices, crop rotation, and pesticides. The following are the most serious diseases of potatoes in the Prairies. Consult your provincial Guide to Crop Protection for a list of chemicals registered for control of potato diseases.

Bacterial Diseases

Bacterial Ring Rot (Plate 12)

Bacterial ring rot is a highly infectious disease caused by the bacterium *Clavibacter michiganensis*, formerly known as *Corynebacterium sepedonicum*. This disease can cause serious losses and is a designated pest in provincial Plant Disease Acts. The Canadian Food Inspection Agency has a zero tolerance for bacterial ring rot in seed potatoes.

Foliar symptoms of the disease vary with the potato variety. Symptoms are not always expressed or may be masked by other stresses on the plant. Ring rot may cause wilting of the lower leaves. Leaves on infected plants yellow and the outer edges may roll up and later become brown and brittle. The lower stem of infected plants will exude a milky ooze when cut and squeezed. Tuber symptoms are noticeable as a cheesy cream-coloured liquid that oozes from the vascular ring when tubers are cut at the stem end and squeezed. As the rot progresses, the vascular ring breaks away from the rest of the tuber. Secondary rot organisms may also infect the tubers and

make it difficult to distinguish the ring rot symptoms. Severely infected tubers turn dark brown or black and completely rot away inside.

During seed cutting, bacteria from infected tubers are smeared on the cutting knives, consequently healthy seed pieces become infected. Ring rot bacteria can survive for five years in dried potato stems and for two years on dry burlap, plastic or plywood surfaces. The bacteria however, live only a short time in soil and are normally killed between fall and winter if all plant debris is ploughed down. Ring rot bacteria can over-winter in infected tubers that survive the winter in the field or in cull piles.

Control Strategies:

- Plant certified seed
- Thoroughly clean and disinfect equipment, tools, trucks and storages with a quaternary ammonium disinfectant (see section 3.2.3 *Sanitation, Handling and Storage of Seed Lots*), or limit movement of machinery and personnel between operations (especially seed)
- Dispose of any crops infected with ring rot
- Dispose of mildly infected crops by processing out-of-field rather than out-of-storage
- Sprout inhibit infected potatoes, so they will not grow
- Plant crops other than sugar beets after potatoes
- Plough under infected potato debris or unharvested potatoes prior to winter
- Allow at least one year before replanting potatoes in an infested field
- Dispose of all used potato sacks or bags
- Destroy cull piles by freezing or burying

Bacterial Soft Rot (Plate 13)

Bacterial soft rot is a common and often serious disease that can affect tubers in storage, in the ground prior to harvest, or seed pieces after planting. The bacterium *Erwinia carotovora* var. *carotovora* and certain other species of soil and tuber-borne bacteria cause bacterial soft rot. Infected tuber tissue is cream to tan in colour and has a soft granular texture. Bacterial soft rot commonly invades tubers that have been frozen, those that have moisture on the surface, or have damaged skin due to mechanical damage or infection by other pathogens. Tubers infected with *Pythium* leak, pink rot, ring rot, *Fusarium* dry rot, or late blight are prone to soft rot. When cold seed pieces are planted into warm, moist soil, moisture may condense on the surface of the seed piece and favour soft rot development. Bacterial soft rot is also common in tubers harvested from waterlogged soils.

Soft rot may also cause rapid and severe breakdown of washed and packaged fresh-market potatoes if they are

not completely dried prior to packaging. Early season potatoes with immature skin are most susceptible to this type of soft rot.

Control Strategies:

- Prior to planting, warm seed tubers to approximately the same temperature as the soil, to reduce condensation on the tubers, which promotes rot
- Clean and disinfect seed cutters, handling equipment, and trucks
- Minimize mechanical damage during harvesting, handling, and packing operations
- Avoid frost injury and properly dry frozen tubers in storage. (See section 3.9.4 *Special Storage Problems*).
- Use clean water that is changed often or chlorinated during washing operations
- Remove potato cull piles, discarded vegetables and plant refuse from fields and storage
- Control other tuber diseases
- Prevent condensation water from forming on tubers by ensuring that cold tubers are ventilated with cool air.

Blackleg (Plate 14)

Blackleg is a common disease of potato caused by the bacterium *Erwinia carotovora* var. *atroseptica*. Symptoms of the disease are noticeable as soft, water-soaked dark brown to black lesions on the stem. Under humid conditions, infected stems may be slimy, but appear shrivelled under dry conditions. Tuber soft rot may also develop. Blackleg bacteria over winter in the soil and on tubers. Tuber borne bacteria are spread during seed cutting, handling, and planting.

Control Strategies:

- Plant blackleg-free, certified seed
- Clean and disinfect seed cutters, handling equipment, and trucks
- Plant in warm soil
- Prevent stem damage during cultivation, roguing and harvesting
- Rogue diseased potato plants, ensuring they do not come into contact with other plants in the field (see section 6.3.2 *Disease Prevention, Roguing and Insect and Irrigation Management*).

Common scab (Plate 15)

The bacteria *Streptomyces scabies* cause common scab. The scab organism is widespread, occurring naturally in soil where it lives on plant debris. The pathogen causes scab-like lesions on the tuber, which vary in type: erumpent (slightly raised), russet (superficial), and sunken (pitted). Lesions may be circular, but often coalesce to

form large, irregular patches on the tuber surface. Scab does not affect yield directly but reduces quality, and may result in higher grade-out. Common scab is more prevalent under hot, dry conditions and in soils with high organic matter. The organism prefers a pH of 5.5-8.

Control Strategies:

- Plant disease-free seed into non-infested soil
- Beginning at tuber initiation, maintain high soil moisture for 4-6 weeks
- Increase time between potato crops to 3-4 years
- Plant early, harvest early
- Plant less susceptible cultivars such as Russet Burbank

Fungal Diseases

Early blight (*Alternaria solani*) (Plate 16)

Each season, early blight causes significant yield losses on the Prairies. The pathogen causes dark brown to black concentric lesions on leaves and elongated brown or black lesions on stems and petioles. Leaf lesions become angular if a large vein retards them. The lesions enlarge, join together and may cover the entire leaf, which will eventually die. The pathogen may occasionally cause sunken circular to irregularly shaped lesions with a raised purple to brown border on the tuber, however, these symptoms have never been reported in Western Canada. The fungus can survive over winter in soil or on plant debris and initiate infection in the crop. Lesions on infected potato plants produce spores that spread to healthy plants and cause infection. The pathogen attacks weaker tissues; young tissue with high nitrogen content is somewhat resistant to the disease. Alternating wet and dry conditions and temperature between 64 and 77°F (18 and 25°C) are very favourable for disease development during the growing season.

Control Strategies:

- Plant disease-free seed
- Maintain good soil fertility and crop vigour
- Harvest when skin is mature to avoid bruising and in turn infection of tubers
- Avoid continuous potato rotations (i.e. planting potatoes in subsequent years in the same field)
- Apply protectant fungicides to the foliage, and follow a fungicide program throughout the growing season. Consult the provincial Guide to Crop Protection for registered fungicides

Fusarium dry rot, seed piece decay, and wilt (*Fusarium* spp.) (Plate 17)

Potatoes can be infected by different *Fusarium* spp. throughout the season. The various *Fusarium* pathogens cause seed-piece decay, wilt, and dry rot. The disease may initiate from infected seed or from inoculum present in the

soil. Wounding is necessary for the development of dry rot and seed piece decay. Wounds to seed pieces at planting are ports of entry for the pathogen to cause seed rot. Wounding at harvest leads to dry rot development in storage. Vascular wilt develops as a result of soil-borne *Fusarium* infection of the roots. In the field, the symptoms of *Fusarium* wilt resemble those of *Verticillium* wilt, and a lab test is required to distinguish these diseases. Tuber yield and quality may be reduced due to wilt, but this disease is not as common as *Fusarium* dry rot.

Control Strategies:

- Avoid wounding tubers at any stage of cropping cycle
- Provide conditions that encourage proper wound healing
- Use registered fungicide seed treatments
- Avoid planting in extremes of cold or hot and dry or soggy soil
- Harvest in dry and cool weather
- Promote wound healing after harvest: 50-55°F (10-13°C) relative humidity at 95% with plenty of air for 10-14 days
- Apply post-harvest fungicide (resistance of *Fusarium* spp. to thiabendazole may reduce effectiveness)

Late blight (*Phytophthora infestans*) (Plates 18, 19 & 20)

Late blight is one of the most devastating diseases of potatoes. The pathogen can infect all parts of the plant. Depending upon the environmental conditions and age of the tissue, appearance of the lesions may vary. The disease starts as small necrotic spots, which may or may not be surrounded by a pale green border. Lesions may also start as small water soaked areas at the tips of the leaf and enlarge inward. Older lesions generally have a necrotic centre and a pale green border. Dark green to black water soaked lesions develop on stems and petioles. Stem and petiole infections destroy soft tissue and leave only structural parts of the stem. As a result, stems remain standing in heavily infested, defoliated fields. Under humid conditions, a white fluffy growth appears at the lesion edges on the under side of infected leaves.

Tubers near the soil surface can be infected if they are exposed or spores are washed into the soil. An irregular and shallow (1/4-1/2 inch, 4-13 mm) coppery brown dry rot spreads through the outer tissue of the tuber. In storage, infected tubers are susceptible to secondary rots caused by other fungi and bacteria; this can result in extensive damage.

The late blight pathogen can survive only in living host tissue. It is known to over-winter in seed tubers, cull piles, and volunteer potatoes that over-winter in the field.

High humidity and temperatures of 64-71°F (18-22°C) are ideal for development of this disease.

Control Strategies:

- Use certified disease-free seed
- Destroy cull piles by freezing or deep burying
- Destroy volunteer potato plants in nearby fields
- Throughout the season, destroy (desiccate, disc or flail and desiccate) infected plants to avoid spread
- Reduce periods of leaf wetness and high humidity within the crop canopy by appropriately timing irrigation
- Follow a recommended fungicide spray program. The program should start prior to the arrival of the pathogen. Consult your provincial Guide to Crop Protection for registered fungicides.
- Consult your local late blight forecast for disease risk information, if available
- Desiccate vines prior to harvest (refer to section 3.8.3 *Vine Killing*).

Leak (*Pythium ultimum*) (Plate 21)

Leak is a tuber disease that has the potential to cause significant storage losses. Diseased tissue of tubers infected with leak is soft, watery, granular and dark grey or black in colour. Severely infected tubers may drip or leak, however, in less advanced stages, infected tissue may only be seen when tubers are cut. There is usually a distinct line between healthy and diseased tissue. Tubers may develop soft rot, and then become slimy and foul smelling. The fungus is present in many soils where it over-winters in plant debris, particularly in wet soils. Tubers become infected through wounds in the periderm. The incidence of leak increases with warm temperatures, as 77-89°F (25-30°C) is ideal for disease development.

Control Strategies:

- Grow potatoes on well-drained soils
- Harvest when tubers are mature
- Harvest below a tuber pulp temperature of 65°F (18°C), especially if the soil is moist
- Grade infected tubers prior to storage to reduce spread to healthy tubers
- Store tubers promptly after digging at recommended temperatures and humidity
- Cool tubers harvested in hot sunny weather to below 50°F (10°C) and market immediately
- Consult your provincial Guide to Crop Protection for registered fungicides

Pink Rot (*Phytophthora erythroseptica*) (Plate 22)

The symptoms of pink rot are typically observed in tubers, but severe infections may develop foliar symptoms such as wilting, yellowing, and aerial tubers. Infected tubers exude a clear, watery liquid. The tissue remains intact, but has a rubbery texture. When infected

tubers are cut open, a pink colour develops within 30 minutes, and later turns black. The tuber decay may proceed into the tuber from the stolon end, and a line may be visible between healthy and infected tissue.

The pink rot pathogen lives in soil and can infect any below ground part of the plant. The pathogen thrives in wet, poorly drained soils and disease progresses quickly during warm temperatures. The disease can spread to healthy tubers during harvest and storage.

Control Strategies:

- Plant in well drained soils
- Avoid wounding during harvest and handling
- Grade infected tubers prior to storage to reduce spread to healthy tubers
- If pink rot infected areas of fields are identified or suspected, market directly after harvest. If this is not possible, store separately from healthy tubers
- Use a fungicide registered for pink rot control. Consult your provincial *Guide to Crop Protection* for recommended products.

Powdery scab (*Sclerotinia sclerotiorum*) (Plate 23)

This disease has been a serious problem for potato growers in New Zealand and parts of Europe for many years, and has recently been recognized as a problem in North America. Powdery scab is caused by the fungus *Sclerotinia sclerotiorum*. It produces a resting spore stage (spore balls) that can survive in soil for at least six years. Initial infection occurs at early tuber set, and is favoured by high soil moisture and soil temperatures of 57-64°F (14°C-18°C). The pathogen causes scabs that are initially rounded and discrete, with torn edges of potato skin surrounding the scabs. Lesions frequently form in a band around the tuber or are clustered at one end. Later lesions may coalesce. By harvest time a dry, powdery mass of spore balls may be present in the scab lesions. The presence of these ovoid spore balls, visible under a dissecting microscope, is necessary for a positive identification of the pathogen. It is possible to confuse powdery scab lesions with those produced by common scab. Powdery scab also infects root tissue, forming galls 1/8-3/8" (1-10 mm) that produce spore balls that remain in the soil at harvest. Powdery scab infections increase grade-out, and the scabs may allow entry of secondary rot organisms. The powdery scab fungus is also the only known vector of potato mop-top virus (Refer to the section on mop-top virus).

Control Strategies:

- Plant disease-free seed into non-infested soil
- Reduce soil moisture levels at tuber set
- Plant late to increase temperature at tuber set, harvest early

- Increase time between potato crops to at least 6 years
- Plant less susceptible cultivars such as Russet Burbank
- No registered fungicides are available (as of December 2001)

****Differentiation between common and powdery scab is important to allow correct management decisions to be made.**

Rhizoctonia stem canker and black scurf (*Rhizoctonia solani*) (Plate 24)

The symptoms of the disease include development of rusty brown lesions on underground stems and stolons and black sclerotia (fungal bodies) on progeny tubers. The leaves may turn pale green or purple and become curled and upright. Development of aerial tubers in leaf axils may also be observed. Under humid conditions, a white cottony growth develops on the lower stem. The disease initiates from black fungal bodies present on infected seed or from the pathogen present in the soil on plant debris. Cooler conditions at planting favour the development of *Rhizoctonia*. Delayed emergence increases the likelihood of infection.

Control Strategies:

- Use only certified and black scurf-free seed
- Use a four year rotation, preferably with cereals
- Plant in warm (60-68°F or 16-20°C), well-drained soil
- Treat seed tubers with a registered fungicide seed treatment
- Harvest the tubers as soon as they are mature, within 4 weeks of vine kill

Seed-Piece Decay

Several species of soil and seed-borne fungi and bacteria cause seed-piece decay. Seed-pieces may develop dry rot or soft rot depending upon the microorganisms involved. Consult individual diseases for their seed piece decay phase.

Control Strategies:

- Avoid bruising the seed
- Preferably plant whole seed
- If using cut seed, follow proper cutting, fungicide seed treatment and storage procedures (see section 3.2.5 *Seed Cutting*)
- Prevent condensation on the surface of the seed by warming the seed near to soil temperature prior to planting, and plant in a warm, moist-but-not-wet soil to promote wound healing and rapid sprout growth. If soil temperature is too cold (below 50°F or 10°C) cut seed will not suberize, if it is too warm (above 64°F or 18°C) it is very favourable for

multiplication of pathogens.

- Avoid exposure of cut seed to hot sun or drying winds

Silver scurf (*Helminthosporium solani*) (Plate 25)

This is a disease of the potato skin. The disease has markedly increased since the early 1990s due to the development of resistance in isolates of the pathogen to thiabendazole (Mertect), the only fungicide that was recommended for control of this disease. The skin spots, which are small and pale brown at harvest, enlarge during storage. Older lesions appear silvery, especially when wet. The disease, though more pronounced on white or red-skinned tubers is also found on russet-skinned cultivars. Although the pathogen can survive on plant debris in soil, the diseased seed tubers are considered the most important source of silver scurf initiation in the field. Under warm and humid conditions, the pathogen multiplies and infects daughter tubers. Delayed harvest, especially after vine kill, increases the disease severity. New tubers can be infected during harvest by intermingling with diseased tubers and during the first 2-3 weeks of storage. The pathogen can survive on structural material.

Control Strategies:

- Plant certified silver scurf-free seed
- Treat seed tubers with a fungicide seed treatment registered to control silver scurf.
- Avoid planting potatoes in a field that had silver scurf the previous season
- Apply post-harvest fungicide treatments to newly harvested tubers (resistance in pathogen populations to thiabendazole may reduce effectiveness of this fungicide)
- Thoroughly disinfect storages before filling
- Harvest as soon as possible after vine kill or maturity
- Reduce the amount of soil and plant debris going into the storage
- Use air to dry wet tubers
- Remove field heat from tubers as soon as possible, and avoid conditions that promote condensation in storage.

Verticillium wilt (*Verticillium spp.*)

Verticillium wilt of potato can be caused by *V. dahliae* or *V. albo atrum*. The disease can have a significant impact on the crop by reducing both tuber yield and quality. Plants infected with wilt start to show symptoms in the middle of the growing season. Individual leaves first turn pale green or yellow, leaves on affected stems then wilt, and finally the entire plant dies prematurely. Initial symptoms often develop on one side of the plant. The lower stems of diseased plants and tubers have brown discoloration in the vascular tissue when cut open.

Verticillium spp. are soil-borne fungi and once established, can live for long periods in the soil even if a potato crop has not been planted for many years. The pathogen can become established in a field through the use of infected seed or by movement of infested soil.

Control Strategies:

- Maintain fertility at levels optimum for high yield
- Irrigate to reduce moisture stress after flowering and during tuber bulking, but do not over-water
- Disease severity may be reduced by incorporating green manure crops in the season prior to potato production
- Practice at least a three year rotation, and preferably a four year rotation
- Do not contaminate clean fields with soil from diseased fields, diseased tubers or plant refuse.

Viral Diseases

Of the more than 27 viruses that have been reported to infect potatoes, potato leafroll virus (PLRV) and potato virus Y (PVY) are distributed worldwide and have often been reported to be the most damaging. These are the two most economically important viruses in the Prairie potato crop.

Potato Leafroll Virus (Plate 26)

PLRV is an aphid-transmitted virus. Primary symptoms appear after the virus is transmitted from an infected aphid to a healthy plant. Primary symptoms include upright, rolled leaves and slight yellowing that appears mainly in the young leaves. In some cultivars, young leaves are pink to reddish beginning at the leaf margins. Leaf rolling may only be evident at the base of the leaflet rather than the whole leaflet, and may eventually spread to the lower leaves. Plants infected early in the season may also be dwarfed. In late season infections, primary symptoms may not appear, as potato plants develop resistance to foliar infection with age, which makes diagnosis difficult.

Secondary symptoms occur when an infected tuber produces an infected plant. Leaf yellowing, along with leaf rolling are often associated with the lower leaves. Leaves are dry, stiff and leathery, and make a paper-like, crisp sound. Plants are often stunted. Secondary symptoms are not as evident in the top of a plant.

PLRV causes net necrosis in infected tubers, rendering them unmarketable (Plate 27). Internal net necrosis is visible when the tuber is cut and is particularly marked in certain cultivars, the most susceptible being Russet Burbank. Net necrosis causes browning of the vascular system within the tuber and is primarily seen when the virus is spread to healthy plants from aphids. It can be

seen in tuber-borne infected plants if the disease pressure is high. Timing of net necrosis development in the tuber is dependent on the time of infection in the field. At harvest, tubers may exhibit net necrosis if the plant was infected with the virus early in the growing season. If infection occurred in August or later, net necrosis will not likely show up at harvest but will develop later in storage.

PLRV infection may result in reduced tuber size and number, and yield loss can be as severe as 60-90%. PLRV can also result in rejection of seed lots for certification, and infected tubers with net necrosis are not acceptable for processing.

PLRV is spread primarily by aphids that colonize potatoes, but it is also tuber-borne and therefore spread by infected seed tubers. The most efficient vector is the green peach aphid (3.6.2 Insect Management). PLRV is the only known persistently transmitted potato virus. Persistent means that once the aphid acquires the virus, it carries it for life. PLRV is concentrated in the phloem (vascular) tissue of the plant and is acquired only by an aphid that chooses to feed on an infected plant. Once the aphid acquires the virus from an infected plant, at least 24 hours or more are needed until the newly infected aphid can transmit the virus. Long distance spread of the virus occurs by wind-borne winged aphids. Short distance spread occurs by non-winged aphids moving from plant to plant. PLRV is not mechanically transmitted and therefore aphids are solely responsible for the in-season spread of the disease. Sources of PLRV include plants grown from infected tubers and diseased volunteer potato plants.

Control Strategies:

- Plant virus-free, certified seed, remove volunteer hosts, and rogue infected plants early to eliminate virus inoculum.
- Management of aphids is an integral part of PLRV management. Control aphids to eliminate aphid vectors during seed production, during aphid population outbreaks and when cultivars susceptible to net necrosis are grown.
- Scout fields regularly and use established action thresholds to determine when insecticide sprays are recommended

Potato Virus Y (Plate 28)

PVY is a common virus that may infect many crops including potato, tobacco, pepper and tomato. Common strains of the virus PVY⁰ occur worldwide. Primary symptoms of PVY⁰, depending on the cultivar, are necrosis, yellowing of leaflets, mottling, leaf dropping and sometimes premature death. Necrosis may cause leaves to collapse and remain attached to the stem.

Symptoms of secondary PVY^o infection include mottling, crinkling of the leaves, and stunting of the plants. Foliar and stem necrosis may occur. Necrosis following primary infection is usually more severe than following secondary infection. The foliar mosaic symptom (intermingled light green and yellow coloration) may be masked at high (77°F or 25°C) and very low (50°F or 10°C) temperatures, but at high temperatures the disease can be identified by the rugosity (crinkling) of the foliage.

PVY is one of the more damaging potato viruses and can have a significant impact on yield. Infection results in reduced tuber number and size. Complete failure of a potato crop may also occur. PVY can also result in rejection of seed lots for certification.

PVY is an aphid-transmitted virus and spread depends mainly on the presence of winged aphids. PVY is transmitted in a non-persistent manner. The aphid can acquire the virus and infect healthy plants in only a few seconds. After a brief period of feeding on healthy plants, infected aphids rapidly lose their virus charge and must again feed on a PVY infected plant to continue to transmit PVY. To determine suitability of a plant as a host, aphids sap-sample the epidermal tissue of a plant. Many aphid species that don't reproduce on potatoes will sap-sample potato foliage, and during this process can spread PVY.

Control Strategies

- Crop borders planted to non-virus host plants such as soybean or wheat provide a landing site where aphids can "clean" their mouthparts from non-persistent viruses before moving into the potato crop. Spread of PVY in potato from sources outside the field can be reduced by up to 60% by using crop borders.
- Plant virus-free, certified seed
- Plant early and rogue out diseased plants
- Apply effective aphidicides
- Vine-kill as early as possible and continue use of an effective aphidicide if needed until vines are completely dead

Potato Mop-Top Virus (Plates 29, 30 & 31)

PMTV is considered to be an economically important disease of potato. It occurs throughout parts of Europe, South America, Asia, and has recently been detected in North America. PMTV is present in Canada, but the distribution within the country is not known. Foliar symptoms of the disease include dwarfing of shoots resulting in a "mop-top" appearance; pale green V-shaped markings on young leaves; and bright yellow blotches, mottling, rings, and V-shapes on leaves. Tuber symptoms

of PMTV infection may include cracking, internal spots, and necrotic rings or arcs referred to as spraing. Tuber symptoms may be difficult to distinguish from tobacco rattle virus or physiological disorders.

PMTV is spread by *Spongospora subterranea*, the fungus that causes powdery scab. The virus survives in the soil within the spore, and together the spore and virus may remain dormant for many years. Plants become infected with PMTV when virus-carrying powdery scab spores infect potato roots, stolons, or tubers. PMTV is also seed-borne. Symptom expression in foliage and tubers is quite variable and is influenced by the type of infection (soil or seed-borne), cultivar, and environmental conditions.

Control Strategies

- Avoid introducing powdery scab and PMTV into uninfested soils by using disease free seed and sanitation practices. Sanitation should be aimed at preventing the movement of powdery scab infested soil on seed, equipment, and in irrigation water.

Follow control recommendations for powdery scab.

For further details regarding virus management in seed potatoes, please see selected reference number 4.

Selected References

1. Delgado-Sanchez, S. and Grogan, R.G. 1970. Potato Virus Y. No. 37 in: Descriptions of Plant Viruses. Commonw. Mycol. Inst., Assoc. Appl. Biol., Kew, Surrey, England.
2. Stevenson, W.R. (Editor). 2001. Compendium of Potato Diseases – Second Edition. APS Press, St. Paul, MN. 125 pp.
3. Peters, D. 1970. Potato leafroll virus. No. 36 in: Descriptions of Plant Viruses. Commonw. Mycol. Inst., Assoc. Appl. Biol., Kew, Surrey, England.
4. Radcliffe, E.B., Ragsdale, D.W., MacRae, I.V. and Suranyi, R. 1999. Aphid Alert. Recommendations for virus control in seed potatoes. <http://ipmworld.umn.edu/aphidalert/alert7.htm>
5. Waterworth, H.E. and Hadidi, A. Economic losses due to plant viruses. Pages 1-13 In: Plant Virus Disease Control. A. Hadidi, R.K. Khetarpal and H. Koganezawa, eds., APS Press, St. Paul, MN, 684 pp.

Potato Spindle Tuber Viroid

PSTVd is a serious disease of seed potatoes caused by the spindle tuber viroid. The Canadian Food Inspection Agency has a zero tolerance for PSTVd in seed potatoes. Plants infected with PSTVd are upright, dwarfed, and

much thinner than uninfected plants. The stems are often more branched and the branches form very sharp angles where they join to the stem. Affected tubers are dwarfed and are usually narrow and spindle-shaped. Eyes are numerous and the tubers are often cracked. PSTVd is spread by contact, but chewing and sucking insects such as aphids, grasshoppers, Colorado potato beetles, and flea beetles have been implicated in the field spread of this disease. Seed-cutting knives, planters and infected seed (tubers and true seed) also spread PSTVd.

Control Strategies

- Plant certified disease free seed
- Plant whole seed
- Wash knives and other equipment with detergents, household bleach or quaternary ammonia compounds, especially between seed lots
- Control insects
- Remove diseased plants, ensuring that the entire plant is removed.
- Avoid leaf contact by people and equipment during field operations

Environmental Diseases

Blackheart (Plate 32)

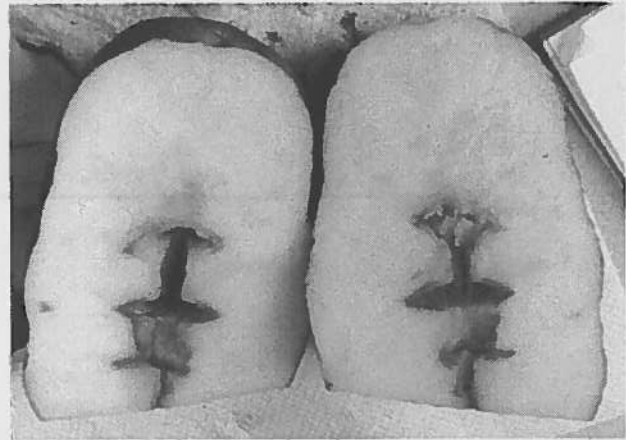
Blackheart results from an insufficient oxygen supply to internal tuber tissue. The centre of the tuber turns blue-black. The tuber tissue associated with blackheart remains firm, as opposed to the black, soft watery tissue resulting from leak infection. Blackheart may develop if tubers are held in low oxygen environments. This can occur in less than ideal storage conditions, water logged soils, or if condensation forms on tubers. Blackheart is prevented by proper ventilation, storing at recommended temperatures, and improvement of soil drainage.

Hollow Heart (Figure 3.6-6)

Hollow heart, a cavity near the centre of the tuber, results from rapid tuber growth. The disorder is found primarily (but not only) in large potatoes. Walls of the cavities are white to light brown. The disorder is difficult to detect because affected tubers have no external symptoms. They can only be removed with expensive X-ray grading equipment. Hollow heart is promoted by growing conditions that cause rapid tuber enlargement. Poor stand increases the incidence of hollow heart. To reduce hollow heart:

- Plant susceptible varieties at closer spacings. See section 3.1.4 *Variety Descriptions* for details on varietal susceptibility.
- Maintain uniform soil moisture throughout the entire growing season
- Plant to maximize stand of uniform plants and minimize misses
- Ensure adequate potassium fertility

Figure 3.6-6 Hollow heart (Courtesy of Manitoba Agriculture and Food)



Malformed Tubers

Extreme soil temperatures may cause secondary growth, knobs, and other tuber deformities. Other conditions such as nutrient and water imbalances have also been implicated in irregular tuber development. Growth cracks may arise from rapid tuber growth and are often the result of improper fertilizer placement. To prevent or reduce malformed tubers:

- Maintain uniform soil moisture, particularly during tuber development
- Apply recommended fertilizer rates
- Establish a high stand of uniform plants to control tuber growth rates
- See section 3.1.4 *Variety Descriptions* for details on varietal susceptibility

Low Temperature Injury

Low temperature or freezing injury can occur to potatoes that are exposed to a heavy field frost or to tubers that have been excessively chilled in storage. Frozen tissue, upon thawing, discolours and breaks down into a soft watery mass (Plate 33). Chilling injury often results in streaks of discoloration in the vascular tissue of the tuber. Frozen or chilled potatoes should not be used for seed as cut surfaces may not heal and seed piece decay will result. Low temperature injury losses can be reduced or prevented by:

- Storing at temperatures above 37°F (3.0°C)
- Proper ventilation and temperature control. See Section 3.94 *Special Storage Problems* for more details
- Culling frozen potatoes prior to storage

3.7 Sprout Inhibition in the Field (K. Lockhart)

Sprout inhibition is essential to maintain tuber quality for the table and processing markets stored past January. Sprouting causes tuber dehydration, physiological aging and affects the appearance of the tuber for the table market. Sprout inhibition is achieved through a combination of proper storage management and the use of a sprout inhibitor. There are two sprout inhibitors registered for use in Canada. MH60, which is applied to the crop approximately 2-3 weeks before harvest or vine kill or Chloroprotham (CIPC), which is applied to potatoes in storage (see section 3.7 *Sprout Inhibition in the Field*).

Sprout inhibition is essential to maintain tuber quality for the table and processing markets stored past January. Sprouting causes tuber dehydration, physiological aging and affects the appearance of the tuber for the table market.

Maleic hydrazide (MH), commonly available as Royal @MH60SG, is registered for field application to prevent sprouting in storage. There are many advantages to field applying a sprout inhibitor:

- MH can be applied to very small plots of potatoes.
- Potatoes are not subject to the in-storage stress

associated with CIPC application.

- Storages containing MH60-treated potatoes do not become contaminated with sprout inhibitor residues and pose no restrictions for the future storage of potato seed. CIPC-treated storages are contaminated with sprout inhibitor and should not be used for seed storage until thoroughly cleaned.
- Field treating reduces the likelihood of volunteer potatoes the following spring.

To achieve the best results from MH60 consider the following:

MH60 is translocated from the vines to the tubers. Translocation will only occur if the vines are healthy. Diseases, insect damage, weeds, environmental stress, senescence and poor application interfere with translocation of MH60 and will reduce the effectiveness of the sprout inhibitor.

MH must be applied after tuber formation and cell division are complete. Normally MH is applied at least 2 weeks prior to vine killing, harvest or frost. Tubers should be at least 2.5 inches (6-7 cm) in diameter at the time of application. Incorrect timing can result in a yield loss or inadequate sprout inhibition.

Growers should read the label before applying MH60. Apply Royal @MH60SG at a rate of 2.29 kg/ac (5.65 kg/ha), in a minimum of 27 gpa (300 l/ha) of water by ground equipment, or a minimum of 40.5 l/ac (100 l/ha) by aerial equipment.

3.8 Harvest Management

3.8.1 Harvest timing (B. Geisel)

Conducting harvest in a timely manner is critical in the production of high quality potatoes that are in demand by the market. A timely harvest will not improve the quality of the potatoes, but a crop can be lost if harvest is not timed appropriately. The majority of the cost of producing a potato crop has accrued by the time of harvest and growers should not risk that expenditure and effort by an untimely harvest. The factors that should be considered when planning a timely harvest are:

- Target yield
- Crop maturity
- Soil and tuber temperatures
- Harvest capacity

Conducting harvest in a timely manner is critical in the production of high quality potatoes that are in demand by the market. A crop can be lost if harvest is not timed appropriately.

Ideally, harvest would not begin until the crop has attained the producer's target yield goals, but that is not always achievable for late maturing varieties. The growing season in Western Canada is highly variable and there are not always enough heat units to achieve target yield goals. Delaying harvest will allow for additional growth and yield, but any gains in yield may be offset by losses, if not all of the crop can be harvested and stored because of adverse weather (rain or frost).

Chemical maturity (see section 3.8.2 *Chemical Maturity*) contributes to storability, marketability and processability of the tubers. Delaying harvest will usually improve maturity, but any gains may be offset by losses, if not all of the crop can be harvested and stored because of adverse weather (rain or frost). Crop maturity monitoring does not affect the onset of harvest, just the order which fields are harvested. The grower should harvest the most mature fields first leaving the immature fields to the end of harvest, allowing for more growth.

Harvest temperatures have the greatest influence on harvest timing. The ideal harvest temperature is between 45 and 60°F (7° and 15°C). Tubers warmer than 64-68°F (18-20°C) and under drought stress are susceptible to black spot bruising. Harvesting when tuber pulp temperature exceeds 68°F (20°C) increases the risk of leak and pink rot, which can result in storage decay. Harvesting when the tuber temperature is less than 45°F (7°C) will contribute to the incidence of shatter bruising.

If the tubers are repeatedly chilled below 40 °F (5°C) the concentration of sucrose will be high resulting in poor fry colour. Depending upon hill shape, variety, soil moisture and vine cover; temperatures below 32°F (0°C) will freeze some or all of the tubers, causing the crop to break down in storage. Rarely can a crop with more than five percent frozen tubers be stored successfully.

**Harvest temperatures have the greatest influence on harvest timing.
The ideal harvest temperature is between 45 and 60°F (7° and 15°C).**

To bring a good quality crop into storage, the harvest must take place when soil and tuber temperatures are ideal (see above). The number of days that these temperatures exist in September and early October are limited. The grower must have the capacity to complete harvest before chilling temperatures or frost damage will render the crop unmarketable. In early October, the risk of crop damage is very high and producers should plan to complete harvest before then. When evaluating harvest capacity, the grower must account for some down time due to inclement weather, wet soils and mechanical breakdowns.

3.8.2 Chemical Maturity (M. Pritchard)

The 'chemical' maturity of potato tubers provides a measure of their suitability for long-term storage and processing quality. As potato tubers develop and the crop matures, the amount of free sugars (sucrose, glucose, and fructose) in the tuber decrease. When the sugars drop to a minimum level, the tubers are considered "chemically mature". This stage normally coincides with maximum dry matter accumulation and indicates that the crop is ready for harvest.

Late planting that shortens the growing season, cool weather that delays plant growth, excess nitrogen, and heat stress can cause elevated sugars at harvest. Chemically immature potatoes contain a high concentration of sucrose, which breaks down to produce the reducing sugars glucose and fructose after the tubers are harvested. High reducing sugars in turn result in unacceptable darkening during frying. Storage stresses such as improper handling, cold temperatures, high carbon dioxide, improper sprout inhibitor application, and tuber aging can also increase sugars, especially in tubers, which were chemically immature at harvest.

Chemical maturity is determined by the sugar concentration in the tuber. Analysis of the sucrose and glucose concentrations along with a standard frying test provides useful information in assessing the chemical maturity of the crop and the effect of various

management practices on crop quality. Sucrose concentration gives a good estimate of potential processing quality before harvest while glucose concentration, when measured during storage, gives the best estimate of processing quality of French fry cultivars, specifically Russet Burbank and Shepody. Sucrose monitoring can be used to determine which fields are nearing maturity and glucose monitoring can be used to determine when they have reached a stage of chemical maturity that will ensure optimum processing quality out of long term storage. Different varieties vary in the amount of sugar that is acceptable for processing. For example, chipping potato varieties must have a lower reducing sugar content than those used for French fries.

Determination of sugar concentrations can be accomplished by various technologies. Most processors use some method of sugar analysis. Equipment for this purpose can be expensive although less expensive technologies are available though may be less reliable.

For further information on the relationships between sugars and colour of processed potatoes and on storage of immature potatoes, refer to the following bulletins on the Department of Plant Science, University of Manitoba webpage:

Relationships of Sugars to Colour of Processed Potatoes (http://www.umanitoba.ca/afs/plant_science/extension/potatoessugars.pdf)

3.8.3 Vine Killing (B. Geisel, D. Waterer, M. Dyck)

Timely vine killing is essential in the production of table, chipping and seed potatoes. Vine killing is not always employed in the production of late season maturing French fry processing potatoes. The growing season in Manitoba is short and late season tuber growth is required to achieve an economic yield of processing potatoes, so vine killing is rarely used. The growing season in Alberta is longer, economic yields are achieved early in the season, so vine killing is a more common practice. Vine killing achieves the following:

- Termination of growth to control tuber size
- Termination of growth to set skin, which reduces skinning and bruising during harvest and shrinkage in storage. A requirement for table production.
- Prevents the spread of viral diseases by aphids. See *aphid* section 3.6.2 *Insect Management*
- Reduction in the spread of late blight spores from infected vines to tubers at harvest
- The time between vine killing and harvest allows diseased tubers to rot in the hill before harvest.
- Stabilization of chemical maturity in chipping potatoes

- Reduction in harvest losses by facilitating separation of the tubers from the stolon
- Removal of vine growth that interferes with harvest

If potatoes are not fully mature, vine killing can reduce the yield and specific gravity. Manitoba studies report that vigorous Russet Burbank potatoes develop 5.5 to 8.6 cwt/ac/day (620 - 970 kg/ha/day) in early September. Vine kill during this stage of growth can significantly reduce yield. The extent of yield and specific gravity losses depend upon the following factors:

- Stage of growth at the time of vine killing. The more immature the crop at the time of vine killing, the greater the loss of yield and specific gravity.
- Condition of the crop at the time of vine killing. Yield losses are greatest if the crop is vigorous and capable of further tuber bulking.
- The interval between vine killing and harvest or a killing frost. The longer the interval between vine killing and harvest or frost, the greater the yield and specific gravity losses.
- The effectiveness of the vine killing operation. Mechanical vine killing will terminate growth much more rapidly than chemical desiccation and result in a greater yield loss if carried out too early.

The 'chemical' maturity of potato tubers provides a measure of their suitability for long-term storage and processing quality.

Under rare circumstances, discolouration of the vascular ring can occur after vine killing. Discolouration is confined to the stem end of the tuber, causing problems in processing (French fries and chips) and table markets. Stem end discoloration (SED) has no effect on seed quality. SED is more likely to occur when vine killing is rapid, the soil moisture is low and the weather is hot. To reduce the risk of SED, avoid rapid vine killing methods during hot weather, especially if the soil is dry.

Vine killing is accomplished by chemical desiccation and mechanical methods. Chemical desiccation is the most common method of vine killing. Apply the desiccant 2-3 weeks before harvest to allow for complete vine kill. Plants may continue to bulk after desiccation, so apply in advance of achieving the desired tuber size for seed and table production. Variety, plant vigour and environmental conditions will effect the rate of desiccation. Two chemical desiccants are registered for use in Western Canada. Check the manufacturer's product label for detailed application procedures and rates.

Chemical Desiccation

Reglone produces a moderate rate of vine kill. Two or 3 applications may be required if growth is vigorous. Reglone performs best if applied at dusk with high volumes of water. This allows the product to penetrate the leaves and stems before being activated by the sunlight the following day. As well, best results are obtained after the onset of senescence and adequate skin set has been established.

Liberty produces a slow to moderate rate of vine kill. A single application will usually achieve complete vine kill. Liberty works best when applied during daylight hours, when photosynthesis is taking place. Efficacy is also enhanced when application is delayed until after the onset of plant senescence. Liberty works best when warm and humid. Conditions that impede plant growth will reduce the effectiveness of Liberty. Liberty is not registered for use on seed potatoes.

Mechanical Methods

Two methods of mechanical vine killing are employed on the Prairies. Both are used in conjunction with a chemical desiccant. Rolling vines with rubber tires or crowfoot packer wheels followed by a Reglone or Liberty application produces a moderate to fast rate of vine kill (Figure 3.8-1). Rolling damages the foliage resulting in partial vine kill, but it also exposes more of the foliage to Reglone or Liberty, enhancing the effect of the desiccant. This results in fewer desiccant applications to achieve complete kill and a faster rate of vine kill. The vine roller also seals cracks in the hills, preventing sunlight from contacting the tubers and causing greening.

Figure 3.8-1 Vine roller with crowfoot packer wheels (Courtesy of Gaia Consulting Limited)



The flail vine shredder, which consists of varying knife lengths to accommodate the contours of the hill and furrow, produces a very rapid vine kill. Flailing removes all but 6 inches (15 cm) of the vine. Flailing closer to the hill can uncover and injure the tubers. The debris from

flailing can interfere with the performance of Reglone. A short waiting period may be required for the debris to fall off of the remaining vine before applying Reglone. Do not use the vine shredder in conjunction with Liberty.

Some flail implements are equipped with drum rollers, which seal cracks in the hills, preventing sunlight from contacting the tubers and causing greening. Flailing reduces the desiccant applications required to achieve complete vine kill and provides a significantly faster rate of vine kill. Flailing causes rapid death, so the vine kill procedure can be timed closer to the harvest date than slower vine kill methods. This extends the length of time for tuber bulking and chemical maturation, thus maximizing yield and specific gravity.

3.8.4 Bruise prevention (L. Delanoy)

An excellent crop in the field prior to harvest does not ensure a high profit out-of-storage. A severe frost or excessive precipitation during harvest, which is beyond the control of the grower, can devastate a crop and eliminate any profit. Harvest timing and management, which can be controlled by the grower, also has a significant effect on quality, net yield and profit out-of-storage. Mechanical damage and bruises caused by rough handling during harvest, trucking and piling into storage, will increase the incidence of storage rots, reduce quality, increase grade-out and reduce the value of the crop.

There are two types of potato bruising that occur at harvest. Both types are caused when the potato strikes an object (machinery, soil clods, stones, other potatoes, etc.), however, each type of bruise occurs under contrasting environmental conditions.

Mechanical damage and bruises caused by rough handling during harvest, trucking and piling into storage, will increase the incidence of storage rots, reduce quality, increase grade-out and reduce the value of the crop.

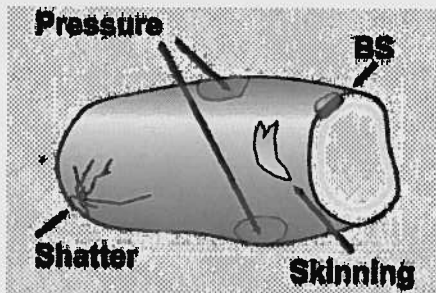
Blackspot Bruising (Figure 3.8-2)

Blackspot bruising occurs under warm dry soil conditions. Susceptibility increases with increasing tuber temperature and decreasing soil moisture and water content in the tuber. The impact ruptures individual cells below the skin of the tuber without breaking the skin. These bruises are not immediately visible. After two days the damaged tissue will turn dark grey or black and can be seen only after the skin is peeled. Varieties vary greatly in their susceptibility.

Shatter Bruising (Figure 3.8-2)

Shatter bruises are thin cracks or splits in the tuber flesh. This is more common on larger tubers. Susceptibility increases with decreasing temperatures below 45°F (7°C) and increasing soil moisture and water content in the tuber. Thumbnail cracks are a form of shatter bruise, which can occur when cold tubers are roughly handled out of storage or on packing lines.

Figure 3.8-2 Blackspot and Shatter bruise (Courtesy of C. Schaupmeyer)



Other forms of mechanical damage include skinning, cutting and scraping. All types of bruises and mechanical damage adversely affect the appearance of potatoes and can result in rot in storage.

The amount of bruising and mechanical damage at harvest is influenced by soil conditions, cultivar, tuber maturity, tuber temperature, and equipment condition and operation at harvest. For detailed harvester adjustments, please contact your local machinery dealer. The following describes how each of the above factors affects bruising potential at harvest:

Soil Clods

Field preparation or in-row tillage performed under wet soil conditions can produce soil clods. Soil clods will persist until harvest and contribute to blackspot bruising. Under dry soil conditions, the clods are hard and cause injury when contacting the tubers during harvesting, trucking and storing operations (Figure 3.4-5). Irrigation prior to harvest can soften clods and reduce damage.

Temperature and Moisture

Western Canada potato producers encounter a wide range of temperatures during harvest in September and early October. As indicated above, extremes in temperature cause different types of bruising. Hot and dry soils produce ideal conditions for blackspot bruising. Irrigating before harvest will increase the water content of the tuber decreasing susceptibility to blackspot bruising.

The risk of shatter bruise increases later in the season (late September and October) as soil temperature decreases. Growers should complete harvest early to avoid conditions, which cause this type of bruising. Harvest

date is influenced by factors such as cultivar selection, planting date, fertility, irrigation, and vine killing.

Fertility

Excess nitrogen delays maturity and promotes skinning and blackspot bruising.

Harvester Operation and Adjustment

The harvest operation accounts for the majority of mechanical damage to potatoes. Trucking, piling into storage and handling for market also contribute to bruising. The following points should be considered when preparing and operating the harvester and other handling equipment:

- All chain or conveyor links and flights should be properly padded with the exception of the primary bed.
- Use ample padding on deflectors, sharp edges and any other locations where bruising can occur.
- Adjust the digger blade depth so that potatoes are not be bruised or cut. Operate the blade deep enough to maintain some soil on the primary and secondary bed to cushion the potatoes.
- Adjust the digger blade height on harvesters and windrowers so potatoes do not bump into the front of the primary chain.
- Maintain a proper forward speed to chain ratio to ensure good soil separation and, at the same time, keeping the conveyors as full of potatoes as possible.
- Keep chain agitation to a minimum. Consider installing hydrostatic agitators (shakers) on the primary bed to improved control.
- Keep beds and conveyors sufficiently tight to avoid sagging and whipping.
- Reduce the distance that tubers drop to 15 cm or less including the loading boom. Consider installing deflector lip on the end of the boom to reduce bruising.
- Check frequently for bruising at various points on both harvester and equipment.

Make your employees aware of the causes and consequences of bruising. Train them to operate equipment in a manner to prevent damage to the tubers. Encourage operators to inspect all handling equipment regularly and to inform you of any situations that have the potential to cause bruising. Encourage employees to act as a team to prevent bruising. Since harvest operators cannot see the entire digging operation they must rely on the knowledge and experience of others for feedback. For more information about bruising obtain the fact sheet *Preventing Potato Bruise Damage*, Bulletin 725 from the University of Idaho, Cooperative Extension System.

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3.9 Potato Storage Management

3.9.1 Storage structures and Ventilation

(D. Small and K. Pahl)

Stored tubers are living organisms, which produce heat through respiration and lose moisture (shrink) through respiration and evaporation. An ideal storage environment must be provided if the tubers are to be stored up to 10 months (see section 3.9.2 *Storage Cycle*). Tubers go through four different storage phases (curing, cooling, long-term storage and marketing), each requiring a different environment. To meet all of these requirements the potato storage must be designed to:

- Maintain tubers at a desired temperature by exhausting the heat of respiration and circulating cool fresh air through the pile.
- Maintain a high relative humidity to promote wound healing at harvest and to prevent tuber desiccation (shrink)
- Provide oxygen for tuber respiration
- Remove carbon dioxide, the by-product of respiration and other deleterious gasses, which affect tuber quality.
- Deal with adverse storage conditions where the tubers are wet, rotting, chilled, frozen or too warm.

Stored tubers are living organisms, which produce heat through respiration and lose moisture (shrink) through respiration and evaporation. An ideal storage environment must be provided if the tubers are to be stored up to 10 months.

There are four factors to consider when choosing a potato storage design:

- Style of structure
- Insulation
- Ventilation and humidification
- Options such as auxiliary heating or refrigeration.

Storage Structure

Almost any type of building can be adapted to store potatoes, however, commercial rigid frame steel buildings are not normally used because the exposed steel beams and columns are difficult to insulate. The most common storage buildings are concrete, wood stud and pole frame, and metal quonset. The factors that vary between various building types are capital cost, durability and longevity, and the type of insulation required for the exterior building envelope.

Regardless of the type of building, the design should be undertaken by a Professional Engineer to ensure that the structure can withstand the forces exerted by the stored potatoes, wind and snow. Design and construction can typically require three to four months or more; therefore early planning is required to ensure the storage is ready at harvest time.

Regardless of the type of building, the design should be undertaken by a Professional Engineer to ensure that the structure can withstand the forces exerted by the stored potatoes, wind and snow.

The size of individual bins and storage systems vary widely with the needs of individual producers and the cost of construction. Bin sizes in modern buildings normally range from 40,000 to 80,000 cwt. Potatoes from individual fields often behave differently in storage, requiring individual management. Ideally, the potatoes from each field should be stored in a separate bin, but since smaller bins cost more per hundredweight, storage management is compromised when storing potatoes from different fields in large bins.

An enclosed loading area attached to the storage bin(s) is recommended. This will allow workers to comfortably load potatoes in severe weather and minimize potential problems associated with chilled tubers.

Insulation

Storages must be properly insulated and sealed in order to maintain the environment required to keep stored potatoes healthy. Besides reducing heat loss and thus helping to maintain the desired storage temperature, insulation is also critical in preventing condensation. Condensation water, dripping onto the tubers, will encourage the development of soft rots and can significantly impact potato quality. It is recommended that enough insulation be installed to achieve a minimum thermal resistance (RSI) of 6.1 (R35). This is equivalent to 10 inches (250 mm) fibreglass or 6 inches (150 mm) of polyurethane insulation. Ceiling fans

have also proved beneficial in reducing free moisture on ceiling surfaces and/or the top of the potato pile.

The amount of insulation also impacts interior air quality. Insulation decreases heat loss through the walls and ceilings, resulting in more heat of respiration exhausted from the building via the ventilation system. In extremely cold weather, this allows the ventilation system to bring additional fresh air into the building, thus maintaining adequate levels of oxygen and reducing the level of deleterious gasses such as carbon dioxide.

Ventilation

Ventilation is the most important factor for maintaining correct temperature, relative humidity, and air quality in the storage. It is also essential for managing potential storage problems caused by disease or frost. The basic ventilation system design is similar, regardless of the type of storage structure (Figure 3.9-1). A typical ventilation system consists of intake door(s), fan(s), air plenum(s), ducts, exhaust louvers and a control system. Recommended ventilation rates are listed in Table 3.9-1.

Ventilation is the most important factor for maintaining correct temperature, relative humidity, and air quality in the storage. It is also essential for managing potential storage problems caused by disease or frost.

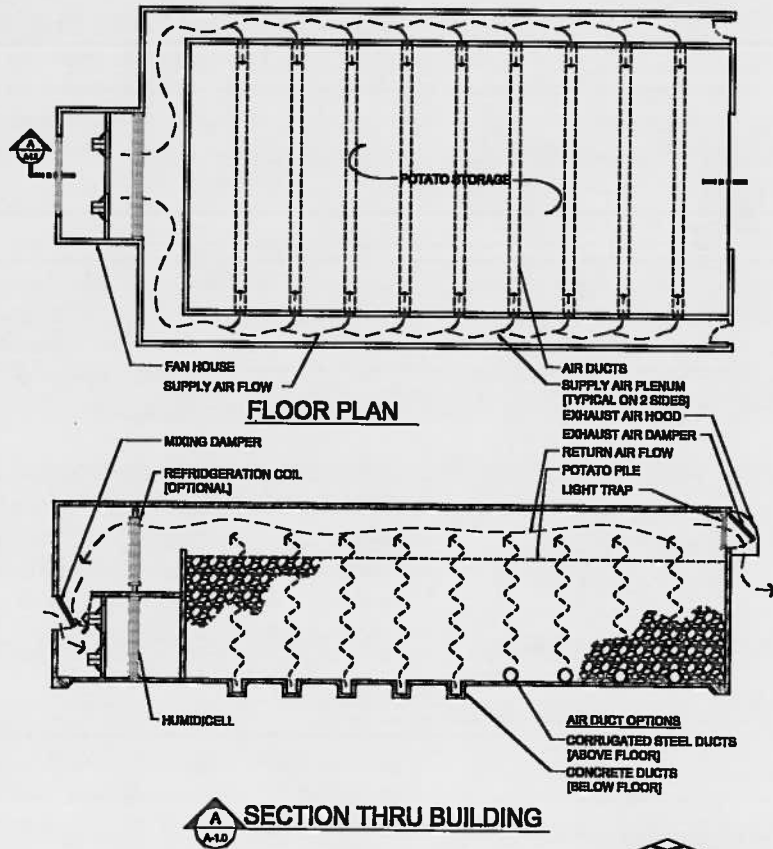
Table 3.9-1 Recommended Ventilation Rates

	L/s ¹	cfm/cwt ²
Seed	75. to 10	0.75 to 1.0
Processing	12.5 to 15	1.25 to 1.5

¹ Litres/second per tonne of potatoes

² cubic feet/minute per hundred weight of potatoes

Figure 3.9-1 Typical Storage Ventilation Design



DGH
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PROFESSIONAL SERVICE - PRACTICAL SOLUTIONS

18 ANDRISON BLVD. ST. ANDREWS, MS 39164 ENG
PHONE (601) 834-8300 FAX (601) 834-8301

18 ANDRISON BLVD. ST. ANDREWS, MS 39164 ENG
PHONE (601) 834-8300 FAX (601) 834-8301

A qualified individual should design the ventilation system. The size of the intake doors, air plenums, ducts, duct outlets and exhaust louvers must be carefully selected to ensure that the ventilation air is evenly distributed throughout the storage. Intake dampers should be designed to close return air supply proportionally as the intake door is opened. As more fresh air intake is required, return air carrying excessive heat or humidity will be forced out of the building through the exhaust vent(s). This can be particularly helpful when trying to remove excessive field heat at harvest. The addition of refrigeration coils, humidification units and light traps in the exhaust louver all impact the resistance to airflow and must be considered when selecting the ventilation fans. Controllers for varying the speed and airflow of the fans are recommended. Contact Manitoba Agriculture or a potato processor for the name of someone qualified to design the ventilation system.

Most control systems utilize a single insulated damper to control the blend of fresh and return air. A heating system, in the perimeter of the damper, is used to prevent freezing of the damper in cold weather. Heavy-duty screw type actuators are used to adjust the position of the damper.

Ventilation controllers vary in complexity, depending on the number of control strategies. The simplest strategy involves running the fans continuously. The volume of air is manually adjusted through the number of fans operating or by adjusting the speed of the fan(s). In this situation, the minimum sensors required are: the temperature control sensor that modulates the mixing damper; a low limit in the supply air to prevent accidental chilling or freezing of the tubers; and an outdoor sensor to prevent outdoor air warmer than the pile from entering the storage.

More advanced systems have carbon dioxide (CO₂) sensors that will activate the damper to bring in fresh air whenever CO₂ levels exceed a pre-set limit.

Few ventilation control systems include a humidistat because they are inaccurate when the relative humidity is >90% and have been of limited value controlling humidity in a potato storage.

Under normal storage conditions, the relative humidity of the supply air should be maintained near 98 percent (see section 3.9.2 *Storage Cycle*). Humidifiers should be installed immediately downstream from the fan(s). Three types of humidifiers are commonly used: high-pressure nozzles, centrifugal spinning disk, and water-saturated fibrous media. The first two types are

used less frequently as they are difficult to regulate, resulting in either too much or not enough water added to the air streams. The third type humidifies the air as it passes through a fibrous media without the pressure of free water droplets that can effect potato quality. This type of humidification unit will create resistance to the airflow and must be sized accordingly. The design of a humidifier is critical and must be undertaken by someone with expertise in ventilation and humidification.

Under normal storage conditions, the relative humidity of the supply air should be maintained near 98 percent. Humidifiers should be installed immediately downstream from the fan(s).

Heat Requirements

Heat from tuber respiration must be removed from the storage to keep the potato pile at the appropriate temperature. Warm air is exhausted and a small amount of cool fresh air is blended with return air to keep the potato pile cool. The quantity of cool fresh air required for temperature control is dependent upon outside temperatures. Under normal storage conditions, no auxiliary heat is required to maintain a constant pile temperature. There are circumstances however where cool outside air in excess of that required for temperature control, is brought into the storage. This situation occurs when:

- Excess moisture must be removed from the storage. Moisture is released into the storage pile when tubers break down from disease or frost; or
- Outside temperatures are extremely cold. Fresh air is brought into the storage to exhaust carbon dioxide and to replenish oxygen.

In these situations supplemental heat is required to warm the incoming air. A heater capacity of approximately 7.5 kilowatts per 10,000 cwt (500 tonnes) of potatoes is normally adequate. Propane or natural gas heaters must be vented to eliminate the possibility of depleting oxygen and increasing carbon dioxide gases.

Refrigeration

Refrigeration should be available for any potatoes stored through the late spring and summer, and can be an asset when trying to remove field heat during a hot harvest season. The basic system consists of an evaporator coil, located in the return air stream, and a compressor/condenser unit located outdoors. The design of a refrigeration system is very complex and should only be undertaken by a person specializing in this area.

The very high humidity in a potato storage requires an evaporator coil with a large surface area to prevent desiccation (drying) of the air, or even worse, frosting of the coil. A minimum capacity of one ton of refrigeration per 2,000 cwt (0.4 kW per tonne) of potatoes is recommended. Note this capacity is only adequate for healthy, high quality potatoes. It may not maintain potatoes that are diseased or have broken dormancy.

3.9.2 Storage Cycle (J. Holley)

Several distinct storage phases exist. The best management practices of each stage depend on tuber conditions, weather and the intended use of the crop. These conditions and related management practices are summarized in table 3.9-3 and discussed below.

Pre-harvest Period

Management over the entire growing season affects the storability of potatoes. Most storage problems usually start in the field before harvest begins. Growers should aim to place a mature, disease and bruise free crop into storage. Research has demonstrated that potatoes from healthy vines are much more resistant to storage decay than potatoes from vines that have been weakened from physiological stress or from foliar diseases, e.g. early or late blight. Good storage design and management practices help to lessen the effects of problem tubers, but storage will never improve a poor-quality crop.

The storage should be prepared well in advance of harvest. Check all mechanical systems and clean and repair ducts. Use an accurate thermometer to check ventilation controls and check operation of the humidification system.

Management over the entire growing season affects the storability of potatoes. Most storage problems usually start in the field before harvest begins.

Growers should aim to place a mature, disease and bruise free crop into storage.

Thoroughly clean then disinfect the storage, handling and harvesting equipment with a quaternary ammonium compound such as Ag-Services Incorporated General Storage Disinfectant, Bardak 2210 Disinfectant Sanitizer, or DMR-23 Disinfectant. Since most disinfectants are inactivated by soil and plant debris, it is essential that this material be removed by thoroughly cleaning equipment and storage with a pressure washer or steam cleaner before the disinfectant is applied. Surfaces must remain wet for at least 10 minutes for the disinfectant to destroy disease organisms.

Harvest Period

Vine killing is not employed in all types of potato production (see section 3.8.3 Vine Killing) When vine killing, desiccate or flail far enough in advance of harvest to allow potato vines to dry as much as possible, and for the skin to set. Tubers with mature skin are more resistant to mechanical damage, bruising, shrink and pathogens (e.g. late blight, leak or pink rot), which cause tuber decay in storage.

Storage management is easier and the quality of potatoes coming out of storage will be better if steps are taken to reduce bruising, mechanical injury and infection from diseases at harvest. The ideal harvest temperature is between 50 and 59°F (10° and 15°C). To avoid shatter bruises, do not harvest when the tuber pulp temperature is less than 41°F (5°C). Tubers warmer than 64-68°F (18-20°C) and under drought stress are susceptible to black spot bruising. Harvesting when tuber pulp temperature exceeds 68°F (20°C) increases the risk of leak and pink rot diseases, which can result in extensive storage decay. Don't bring severely frosted, chilled or diseased potatoes into storage. For more information see *Reducing Harvest Damage* in section 3.8.4 *Bruise Prevention* and section 3.9.4 *Special Storage Problems*.

Post-harvest Curing Period

The greatest amount of shrink occurs after harvest and before curing is complete. Harvested potatoes are skinned and there is no barrier to moisture loss until suberin is formed over the wounds. This initial storage period promotes wound healing (suberization) and skin set, which are critical for long-term storage quality of potatoes. The temperature, relative humidity and length of the curing period are determined by the condition of the harvested potatoes. High humidity (95%) during the curing period is critical to prevent excessive shrinkage and to promote wound healing. Mature, healthy potatoes should be cured for about two weeks at 50-60°F (10-15°C) and 95% relative humidity.

The greatest amount of shrink occurs after harvest and before curing is complete. Harvested potatoes are skinned and there is no barrier to moisture loss until suberin is formed over the wounds.

Immature potatoes with high sugars should be cured for an extended period of time at 60°F (15°C) and 95% relative humidity until fry or chip colour is acceptable (see section 3.9.3 *Storing Chemically Immature Potatoes*). Frozen or rotting tubers should be cured at a lower temperature and relative humidity (see section 3.9.4 *Special Storage Problems*) and marketed as soon as possible.

The ventilation regime used during curing is determined by the cooling requirement and the need to provide fresh air (oxygen) to the tubers. Ventilate to maintain the pile at the desired suberization temperature. You may have to ventilate more frequently if there is condensation on the surface of the tubers. Sweating or condensation on surface tubers occurs when the upper tubers are cooler than those inside the pile. A small amount of free water is usually harmless, but any excess surface moisture will encourage soft rot. Continuous ventilation is recommended when condensation is present.

Cool tubers as quickly as possible from field temperature to curing temperature. Never cool with outside air that is significantly colder than the desired storage temperature, as tubers near the air ducts will be chilled. Plenum temperature should be no lower than 3-5°F (1.5-3°C) below tuber temperature.

Tubers that are harvested cold should be warmed to the desired curing temperature at a rate of about 2°F (1°C) per day, then suberized (see section 3.9.4 *Special Storage Problems*). Warm air will cause condensation on the cool tubers, making them more susceptible to soft rot infection.

Following the curing period, the potatoes should be cooled to the long-term storage temperature at a rate of 4-5°F (2-3°C) per week. Rapid cooling can cause colour problems in processing potatoes.

Mid and Long-Term Storage

The objective of long-term storage is to maintain a consistent, ideal environment for the duration of the storage period. Long-term storage demands more critical control than short-term storage. Recommended storage temperatures depend upon crop condition, variety and intended end use. General recommendations for storage temperatures are listed in table 3.9-2. A 2°F (1°C) difference between pile top and bottom is acceptable.

Table 3.9-2 Long Term Storage Temperatures

Seed potatoes	36-39°F	2-4°C
Table stock	38-41°F	3-5°C
Processing		
-French fries	45-48°F	7-9°C
-Shepody	48-50°F	9-10°C
-Chips	45-50°F	7-10°C

Ventilation can be either intermittent or continuous. When storing healthy mature tubers, ventilation at intervals of 8 - 12 hours per day at full airflow rates is sufficient to maintain pile temperature. However, continuous ventilation maintains more uniform storage

temperatures, particularly when outdoor temperatures are extremely low. Reducing airflow through the pile can minimise weight loss in storage. One way of accomplishing this is to operate fewer fans.

Maintain a relative humidity of 95% or higher unless special storage disorders are present.

Marketing Period

Reconditioning is a storage procedure that improves chip or fry colour. Reconditioning is accomplished by increasing storage temperatures to 50-64°F (10-18°C) for two to four weeks before marketing. The higher temperatures increases tuber respiration rate, which reduces sugar levels and improves chip or fry colour. Growers are advised to consult the processor prior to reconditioning as problems can develop when tubers are exposed to reconditioning temperatures. Higher storage temperatures increase shrinkage and rot, reduce specific gravity and may break dormancy of sprout-inhibited tubers. Potatoes may require immediate processing if serious storage decay develops. Reconditioned tubers should be processed within one month; otherwise a condition called irreversible senescence sweetening may occur. A storage facility containing several smaller (30,000 cwt or 1,360 t) bins is far more flexible with respect to reconditioning than a storage facility with only one or two 60,000 cwt (2,720 t) bins. Small bins can be individually reconditioned (warmed) prior to opening and moving.

Seed potatoes, marketed late in the season, should also be pre-warmed to break dormancy prior to planting and to reduce injury during handling.

3.9.3 Storing Chemically Immature Potatoes (M. Pritchard)

Weather conditions or management practices sometimes delay crop maturity. Prompt harvest before the crop reaches chemical maturity may be necessary to avoid autumn frosts. Alternative storage management steps may be required to ensure that chemical immaturity (high sugars) of tubers does not affect processing quality out of long-term storage. Chemical immaturity can cause excessive accumulation of the reducing sugars, which results in darkening of potato products during frying.

Processing tubers are usually held at storage temperatures near 59°F (15°C) with Relative Humidity near 95% for up to two weeks after harvest to promote suberization and wound healing. This *curing or preconditioning* period may need to be extended if tubers are chemically immature at harvest to prevent excessive

reducing sugar accumulation in storage. During this period, sugars are either used up in respiration or are converted into starch. Depending on how much sugar is in tubers at harvest, it may take several weeks of preconditioning before reducing sugars begin to decrease and it may take several more weeks before they have dropped to a level acceptable for processing.

Extended preconditioning would not be recommended for severely diseased tubers or tubers which have been damaged by frost. Prompt marketing of such tubers would be recommended. Tubers can also be *reconditioned* prior to marketing, which involves gradually raising the storage temperature to lower sugars that accumulated during storage. Reconditioning just before sale may be preferred for diseased or frosted tubers since storage losses may be excessive if tubers are held at high temperatures for extended periods after harvest.

Long exposure of stored tubers to high temperatures will increase the chance of weight loss due to respiration and water loss. The more physically and chemically immature the tubers at harvest, the greater the weight loss. However, the additional weight loss during preconditioning or reconditioning is justified if processing quality is improved.

For further information on storage of immature potatoes refer to the following bulletins on the Department of Plant Science, University of Manitoba webpages: *Storage of Immature Russet Burbank and Shepody Potatoes* (http://www.umanitoba.ca/afs/plant_science/extension/potatoesstorage.pdf).

3.9.4 Special Storage Problems (D. Schwarz and B. Geisel)

Storage problems most often occur because of conditions in the field and not conditions in storage. Adverse weather, disease or improper harvesting and handling of tubers can cause problems in storage. Tubers that are rotting, frozen, chilled or diseased must be managed differently than mature, sound tubers. Good storage management will help to salvage problem tuber lots, but storage will never improve a poor quality crop. A summary of the techniques used for storing problem potatoes is included in table 3.9-3.

Good storage management will help to salvage problem tuber lots, but storage will never improve a poor quality crop.

3.9.5 CIPC Sprout Inhibition (R. Dreger)

Sprout inhibition is essential to maintain tuber quality for the table and processing markets. Sprouting causes tuber dehydration, physiological aging and affects the appearance of the tuber for the table market. Sprout inhibition is achieved through a combination of proper storage management and the use of a sprout inhibitor. There are two sprout inhibitors registered for use in Canada. MH60, which is applied to the crop approximately 2-3 weeks before harvest or vine kill (see section 3.7 *Sprout Inhibition in the Field*) and Chloroprotham (CIPC), which is applied to potatoes after harvest.

CIPC is available either as an aerosol or an emulsifiable concentrate. CIPC aerosol may only be applied to stored potatoes by trained applicators using specialized equipment. The grower applies the emulsifiable concentrate as a direct spray onto fresh market potatoes during the grading and packaging process. The balance of this section deals with the application of CIPC aerosol.

CIPC aerosol, which prevents cell division, must be applied after wound healing (suberization) and curing and before dormancy breaks. Historically, CIPC aerosol was applied with equipment originally designed for insecticide fogging. The by-products of combustion used to generate the CIPC aerosol have negative effects on potato quality. These by-products include heat, carbon dioxide and ethylene. This problem was resolved by designing an applicator specifically for CIPC aerosol application. The new applicator technology eliminates the deleterious effects of combustion by-products and improves the effectiveness of the treatment. Both the old and new style applicators are used in Western Canada.

Storage managers should contact the custom applicator for specific recommendations before preparing the storage for CIPC application. CIPC has an affinity for water, so the humidifier should be turned off at least two days prior to application to ensure the plenum and air ducts are dry. Before applying CIPC into the potato storage, the custom applicator checks and adjusts the air system, protects the refrigeration coils and reports any factors (disease, dirt, frost damage, etc) that may affect sprout inhibition. If storage conditions are suitable, the storage is sealed and the treatment is applied. After the treatment is complete and the fog has cleared from the storage, the applicator enters the building to perform post treatment cleaning of fans, fan guards, plenum, and other surfaces in contact with the chemical. Sealing materials are removed and the storage controls are reset to pre-treatment conditions, allowing the grower to resume normal operations.

WARNING: Only trained personnel wearing protective clothing should enter the storage during treatment.

Occasionally, CIPC treated potatoes sprout prematurely. Poor performance of the sprout inhibitor could be caused by:

- Temperature fluctuations and “hot spots”. These increase the rate of tuber respiration resulting in poor sprout inhibition. Temperature fluctuations and “hot spots” are caused by an improperly designed or malfunctioning ventilation system or excessive dirt and tuber rot in the bulk pile.
- Physiological stress. Field-stressed potatoes may respond differently to CIPC application than potatoes grown under normal conditions. Studies have shown that potatoes grown with deficient nitrogen will sprout earlier than adequately fertilized potatoes. Other field stresses (disease, drought, excessive moisture, and extreme temperatures) may also reduce the effectiveness of the sprout inhibitor.
- A low CIPC concentration on the sprout can cause internal sprouting where the sprout grows inward into the tuber or outward into an adjacent tuber (Figure 3.9-2). This defect occurs mainly in long-term storage. Late application, pile settling or the presence of excessive dirt and debris may interfere with the application, resulting in a low concentration of CIPC on selected tubers.
- Improper application.
- Poor storage management including fluctuating temperatures, high levels of respiration gases, low humidity, etc. shorten the dormancy period and reduce the effectiveness of sprout inhibition.

Figure 3.9-2 Internal Sprouting



CIPC and Seed Potatoes

Contamination of seed lots by CIPC can occur one or more years after a storage treatment. Do not store seed potatoes in a structure that was recently treated with CIPC or in a structure adjacent to a building where CIPC will be applied. There are no effective methods to rapidly decontaminate a storage structure after CIPC application. Seed can only be safely stored in a structure one year after the fans, ducts, and plenums are thoroughly cleaned of all CIPC residues and warm air has been circulated through the storage during the summer period.

Table 3.9-3 Management of Special Storage Problems

Field or Storage Period	General Requirements	Crop Conditions		
		Normal	Wet soil	Wet Tubers
Pre-Harvest	Repair, clean & disinfect the harvest, handling and storage equipment as well as the storage structure.	Under dry soil conditions, apply pre-harvest irrigation as required to soften clods and prevent black spot bruising.	Segregate affected areas by desiccation or discing.	Do not overirrigate prior to harvest. Keep an eye on low spots to ensure water doesn't pool.
Harvest	Follow best management practices for bruise prevention. Record the harvest conditions (tuber temperature, precipitation, etc.) of each load. Record the location of each field in storage.		Do not harvest segregated areas.	Never harvest when there is precipitation. Tarp loads in case of sudden rain showers and do not windrow too far ahead of the harvester.
Post-Harvest (Curing or Suberization)	Ventilate to bring storage to suberization temperature, suberize for appropriate period then reduce temperature by 4-5°F (2-3°C)/week for long term storage.	Ventilate and humidify (R.H. 95%) to bring storage to suberization temperature [50-60°F (10-15°C)], suberize for 2 weeks then reduce temperature by 4-5°F (2-3°C)/week for long term storage. When humidifying, ensure there is no free moisture dripping onto the tubers.	Ventilate continuously without humidifying to bring storage to suberization temperature [50-55°F (10-13°C)], suberize for two weeks then reduce temperature by 4-5°F (2-3°C)/week for long term storage. Return to normal humidity (R.H. 95%) after soil on tubers is dry.	Market immediately or segregate affected lots in storage. Ventilate continuously without humidifying to bring storage to suberization temperature [50-55°F (10-13°C)], suberize for two weeks then reduce temperature by 4-5°F (2-3°C)/week for long term storage. Return to normal humidity (R.H. 95%) after tuber surface is dry.
Long-Term Storage	Long Term Storage Temperatures: Table 41-43°F (5-6°C), Processing 47-50°F (8-10°C) Shepody 50-54°F (10-12°C), Seed 37-39°F (3-4°C)	Fan operation - continuous or intermittent or reduce fan speed with VFDs (Variable Fan Drives). Inspect storage frequently. Monitor oxygen levels, and add fresh air as necessary. Fresh air may require warming to prevent shocking the tubers. Heaters should be electrical or exhausted to the outside of the storage.		
Marketing	a) Warm to reduce handling damage. b) Recondition. c) Pre-warm to break dormancy.			

Crop Conditions				
Chilled	Frozen	Wet Rot	Dry Rot	Hot Tubers
Plan to complete harvest before first week in October to avoid chilling.	Potatoes that are hilled properly are less likely to freeze. Plan to complete harvest before first week in October to avoid frost damage.	Segregate affected areas by desiccation or discing.	Under dry soil conditions, apply pre-harvest irrigation as required to soften clods and prevent black spot bruising.	
Dig when tuber pulp temperature is above 41°F (5°C) to avoid shatter bruising.	Dig after tuber pulp temperature is above 41°F (5°C) to avoid shatter bruising. Let frozen tubers rot before harvest, making it easier to identify and grade out before storing.	Do not harvest segregated areas of field. Grade out affected tubers before storing.	Follow best practices for bruise prevention. See x.xx Bruise Prevention for more information.	Do not harvest when tuber pulp temperature exceeds 65°F (18°C). Do not windrow too far ahead in order to keep tubers cool.
Ventilate continuously and humidify (95% R.H.) to warm storage to suberization temperature [39°F (15°C)]. Carry out normal suberization process for table and seed potatoes, and for processing potatoes suberize until fry colour improves. Then reduce temperature by 4-5°F (2-3°C)/week for long term storage. When humidifying, ensure there is no free moisture dripping onto the tubers.	Market immediately or segregate affected lots in storage. Ventilate continuously without humidifying to warm storage to 47-50°F (8-10°C). Consider adding supplemental heat to remove excess moisture. Reduce temperature by 4-5°F (2-3°C)/week for long term storage and return to normal humidity (R.H. 95%) after frozen tubers are mummified.	Market immediately or segregate affected lots in storage. Ventilate continuously without humidifying to bring storage to 47-50°F (8-10°C). Consider adding supplemental heat to remove excess moisture. Reduce temperature by 4-5°F (2-3°C)/week for long term storage and return to normal humidity (R.H. 95%) after affected tubers are mummified.	Apply appropriate fungicides to tubers going into storage. Ventilate and humidify (R.H. 95%) to cool storage to suberization temperature [50-60°F (10-15°C)], suberize for 2 weeks then reduce temperature by 4-5°F (2-3°C)/week for long term storage. When humidifying, ensure there is no free moisture dripping on to the tubers.	Ventilate and humidify (R.H. 95%) to bring storage to suberization temperature [50-60°F (10-15°C)], suberize for 2 weeks then reduce temperature by 4-5°F (2-3°C)/week for long term storage.
<p>Fan operation - continuous or intermittent or reduce fan speed with VFDs (Variable Fan Drives). Inspect storage frequently. Monitor oxygen levels, and add fresh air as necessary. Fresh air may require warming to prevent shocking the tubers. Heaters should be electrical or exhausted to the outside of the storage.</p>				
	Market as soon as possible.	Market as soon as possible		

3.10 Food Safety (L. Delaney and C. Schaupmeyer)

In the process of growing, harvesting, storing and shipping, potatoes are exposed to many conditions that may result in food-safety problems. There are three general types of contaminants that can either reduce quality or actually make potatoes unsafe for consumers.

These are:

- Organisms, such as bacteria, but also larger animals like mice.
- Objects, (foreign materials) such as glass, metal, wood or plastic
- Chemicals, such as disinfectants, cleaners, fuels or pesticides.

Contaminated potatoes can cause illness or injury to a consumer. The presence of physical contaminants can cause losses and equipment failure in processing and packing plants. Awareness, documentation of all practices and a safe-food attitude are important in ensuring food safety on the farm.

In the process of growing, harvesting, storing and shipping, potatoes are exposed to many conditions that may result in contamination causing illness or injury to the consumer. Awareness, documentation of all practices and a safe-food attitude are important in ensuring food safety on the farm.

The following are methods for preventing contamination by microorganisms and other pests:

- Potato storages must be sanitized before potatoes are stored. Walls, floors, plenums and ducts should first be washed with high-pressure water and then a general storage disinfectant.
- Storage cleaning records, which include date and materials used, should be kept. Name of the person doing the cleaning should be recorded.
- Where diseases are known to be present in stored potatoes, trays containing disinfectant (foot baths) should be placed at storage entrances to reduce the risk of spreading diseases to other storages.
- Animals such as mice, gophers, farm pets, and birds must be prevented from entering storages so their feces and carcasses do not contaminate potatoes.
- All work and storage areas should have adequate toilet facilities including hand-washing facilities that include liquid soap dispensers, warm water and disposable paper towels for drying. Staff must wash hands after using facilities.
- Producers who have both livestock and potato

production facilities should have separate footwear for each facility.

- All wash water should be clean and free of microbiological and chemical contaminants.
- Cull piles are a potential source of potato diseases and contamination of stored potatoes. Cull piles should be disposed of away from potato facilities as soon as possible.

The following practices prevent contamination with foreign materials:

- Loose metal objects such as nuts, bolts and nails must be removed from storages prior to storing potatoes. Small metal objects can embed in individual tubers and pass undetected through grading facilities.
- If a grower suspects there could be foreign objects in potatoes, the packer or processor should be alerted. One small piece of metal can cause a costly plant shut down. It also becomes a safety hazard for consumers if undetected.
- Glass cannot be detected with scanning devices in processing plants and is therefore a major concern.
- Standard light bulbs should not be used anywhere in potato storages where glass could fall onto potatoes. Shatter-proof light bulbs should be used over grading lines and in storages or protective shields must cover bulbs.
- Broken glass must be thoroughly cleaned up in a storage complex.
- Plastic film or small plastic objects are potentially as dangerous as metal and cannot be detected with metal detectors common in processing plants.

The following practices prevent contamination with chemicals:

- Chemicals should be stored in well-ventilated areas away from storages. Pest control chemicals must never be housed in a potato storage or receiving area.
- Storage should not be used as a shop or garage at any time.
- If vehicles are temporarily stored in potato storage and handling areas, all traces of grease and oils must be removed prior to storing or handling potatoes.
- All spilled chemicals including oils, solvents, lubricants and cleaners must be thoroughly cleaned.
- If diesel or gasoline fumes are noticeable, the area must be thoroughly aired prior to storing potatoes.
- Pre-harvest or pre-marketing intervals must be adhered to when applying pest control products and sprout inhibitors.

- Use only registered pest control chemicals on potatoes in the field or in storage.
- Sprayers or chemical applicators must be calibrated to ensure rates are accurate. Date of calibration should be recorded.
- Thorough and accurate records should be kept for all fertilizers and pest control products applied to potatoes. Names of applicators should be recorded. Record books specifically for chemical applications are available from dealers and processors. Records of products applied should include information such as:
 - o Fertilizer or chemical supplier
 - o Type of fertilizer and rate applied
 - o Pest-control chemical names and rates
 - o Land locations where products are applied
 - o Dates of application
 - o Name and initials of the applicator

General practices to ensure a safe supply of potatoes:

- Documentation is key for a successful program and will help a producer in the event of a problem.
 - All areas and facilities where potatoes are handled or stored must be clean and sanitary.
 - Develop and maintain a safe food attitude on the farm.
 - Learn how to identify and control potential hazards on the farm.
 - Be aware of potential risks and constantly be on the lookout for hazards to food safety.
- Develop a working environment where staff is encouraged to make suggestions or point out potential risks to the safety of the potatoes grown and stored.

4 Organic and Pesticide Free Production

(L. Delanoy, C. Schaupmeyer and J. Hollinger)

The objective of this section is to make prospective organic potato producers aware of some of the regulatory aspects and general agronomic practices that will assist in the production of "certified organic" potatoes.

Organic potato production prohibits the use of synthetic chemicals, fertilizers, pesticides, growth regulators, or genetically modified varieties. The decision to grow organic potatoes may be based on a personal desire to adopt an organic production system, to capitalize on the demand in the organic marketplace, or for various other reasons.

4.1 Regulations and Certification

Regulations for the production and processing of organic products were established by the Canadian General Standards Board and approved by the Standards Council of Canada in June 1999. Under the "National Standard of Canada for Organic Agriculture" (CAN/CGSB-32.310-99), minimum standards for the organic industry have been outlined. Individual certifying bodies use these regulations as a basis for their own standards, which are often more stringent than those in the National Standard.

A certifying body is a group that provides third-party verification of the organic production process. There are currently over forty such bodies in Canada. Each certifying body has the authority to grant "certified organic" status to any plant or animal product meeting the Regulation CAN/CGSB-32.310-99.

There are several general steps and practices to follow to become a certified organic potato grower.

Market Research

- Market research is an essential step before proceeding with certification or production. Determine the market potential and marketing strategies that will be used to sell your organic products.
- Talk to certified organic producers or processors about their experiences in organic production.

Certification

- Contact a certifying body and obtain copies of the standards and regulations. Familiarize yourself with the standards and guidelines of the certifying body you choose to deal with and develop a long-term strategy for your organic production.

- An independent organic inspector contracted by the certifying body will perform a farm inspection.
- #### Production Research

- Research organic production methods thoroughly. Sources of information include books, fact-sheets, Internet, producer organizations, organic farmers and organic specialists with federal and provincial agriculture departments.
- Attend organic producer organization information meetings and network with other organic farmers and gain from their experiences.

Production

- Plan to start small. Increase the size of the organic operation over several years.
- Grow and market products in accordance with the standards and guidelines established by the certifying body.
- Develop a comprehensive, clear and accessible record-keeping system (audit trail).

Marketing

- Ensure that all labelling complies with guidelines and regulations of the certification body.

4.2 Organic Potato Production Practices

A wide range of insect, disease and weed pests can attack potatoes. The key to successful production of potatoes without the use of synthetic pest control products is prevention and plant nutritional health.

The key to successful production of potatoes without the use of synthetic pest control products is prevention and plant nutritional health.

Experienced potato producers will be aware of the major threats to healthy potato production and know the consequences of aggressive pest attacks. Novice commercial potato producers may not be aware of the destruction of uncontrolled pest invasions and poor plant nutritional health and must be aware of the pitfalls of failing to adequately protect potato crops. Certain pesticides are approved for use by certification bodies. Consult the "Permitted Materials List" of the certifying body before applying a product. Ensure that all products used as pesticides are also approved by the Pest Management Regulatory Agency (PMRA). PMRA is the federal agency that approves the use of all pesticides (organic or synthetic) in Canada. It is against the law to apply a pesticide that is not registered by PMRA.

Overall plant-health considerations

- It is recommended that organic potatoes be grown in a minimum of a 4-year rotation to minimize yield losses from soil-borne diseases such as *Verticillium* wilt, *Fusarium* and *Rhizoctonia*.
- General soil fertility must be maintained by a well-planned management system involving rotations, legumes, straw and composted manure.
- Manure plays an important role in providing plant nutrients, however, organic producers must ensure that the manure has been composted properly and meets the standards approved by the certification authority.
- Organic producers cannot use a fungicide seed piece treatment, so it is recommended that whole seed be planted. Whole un-cut seed tubers are less likely to become infected with soil borne diseases than cut seed pieces. See section 3.2 *Seed Selection, Storage and Cutting* for more details.
- Plant low generation certified seed, which has a lower incidence of seed borne diseases.
- Certain certifying agencies and end-users may require the use of organic seed. Organic producers must clarify this prior purchasing seed.
- Vigorously growing potato plants are more resistant to insects and diseases than plants under stress. For example, the main prevention for early blight is ensuring that a potato crop has an adequate, season-long supply of nitrogen. Adequate soil moisture in the presence of adequate plant nutrition will assist in maintaining overall plant health.
- Potatoes should be planted after risk of frost has passed and when rapid emergence will reduce risks of seed decay.

4.3 Pest management considerations

Insects See section 3.6.2 *Insect Management* for more detailed information.

- The main threat to yield loss is from Colorado potato beetle (CPB).
- *Bacillus thuringiensis* (Bt), a biological insecticide is accepted by many certification agencies, but producers are advised to consult with their own agency as to which Bt strains are approved for use.
- Isolation from production areas with a high density of potato acres will reduce risks from all insect pests.
- Locating a potato field at least 200 - 300 meters from a previous season's field will reduce the population of over-wintering Colorado potato beetle adults and resulting larvae. In spite of the success of this strategy be prepared with a plan to control larvae.

Weed control See section 3.6.3 *Weed Management* for more details about cultural and mechanical weed control.

- In extreme cases, summer fallow the year prior to potato production may be required to reduce weed populations to a point where they will not reduce yields or interfere with harvest operations.
- Post-plant cultivation (hilling, harrowing and hilling) is effective in controlling annual weeds, however, excessive cultivation or cultivation at the wrong time may reduce yield.

Diseases See section 3.6.4 *Disease Management* for more detailed information.

- Low-generation certified seed must be used to reduce the risk of seed-borne diseases.
- Whole seed must be used to reduce risk of spreading disease during cutting.
- Most whole seed pieces will emerge and produce healthy plants. However, some cut seed pieces will always decay resulting in reduced final stand. Plants will grow from seed tubers that are partially decayed, however vigor and yield will be reduced.
- Isolation may reduce the risks from diseases such as late blight.

5 Gourmet Potato Production (L. Delaney and C. Schaupmeyer)

The demand for small, gourmet, fresh market potatoes has increased in recent years. Production of small potatoes can be enhanced through management, although tuber size and number is not entirely under the grower's control. Producers wishing to grow for this specialty market can follow a production plan to produce small potatoes, or they can grade out the small tubers from a mixed size tuber lot. Several factors contribute to small tuber size.

- Crop Stress due to under-fertilization or low soil moisture.
- Short growing season due to early harvest (70 to 90 days after planting) or late planting.
- Tuber set – More tubers per individual plant results in increased competition.
- Plant population – A high plant population produces more daughter tubers per acre (hectare) resulting in increased competition.

The first two factors result in reduced yields and immature tubers, which may not store well. The last two factors result in an increased number of smaller daughter tubers without sacrificing total yield. Growers should employ management practices that increase tuber set and plant population to achieve smaller tubers. These include the following practices, which are discussed below and in table 4.3-1:

- Variety selection
- Seed size
- Seed handling
- Green sprouting
- Irrigation Management

Variety Selection

Certain varieties tend to produce higher tuber numbers (set) than others. For example: Cal Red and Bintje produce a large set, making it suitable for gourmet tuber production. For more information on tuber set characteristics of individual cultivars, refer to section 3.1.4 *Variety Descriptions*.

Seed size

Large, whole seed pieces, between about 2.5 and 3 oz (70-90 g), produce more stems per plant than smaller seed or cut seed. Tuber set (number) is directly related to stem number, therefore the higher the stem count per plant, the higher the tuber set. Growers producing small whole tubers under irrigation should aim to have at least four or five stems per linear foot of row.

Growers producing small whole tubers under irrigation should aim to have at least four or five stems per linear foot of row.

Seed handling

Seed that is warmed or aged prior to planting will produce higher tuber sets than cold or young seed. Warming seed at 50-53°F (10-12°C) for two weeks (or more) prior to planting is recommended. Seed can also be aged by maintaining storage temperatures slightly higher than normal (41°F instead of 37°F or 5°C instead of 3°C) for two to four months during the storage period, however this may result in sprout growth prior to planting time. Seed age is also affected by the warmth and length of the growing season the year before. It is difficult to establish the exact tuber set potential of potato seed tubers.

Green Sprouting

Green sprouting, or chitting, is used to accelerate the emergence and development of potatoes and to increase tuber numbers. Eight weeks prior to planting, seed tubers are warmed to 68°F (20°C) in the dark to promote multiple sprout development. When the white sprouts are 2 to 3 mm long, the seed is exposed to light for 8 to 10 hours per day for two weeks. Seed tubers are placed in wooden trays or mesh bags that are made especially for green sprouting. Green sprouting seed tubers will form short, thick, sturdy, green sprouts, which will remain intact during planting.

Irrigation

Research studies have shown that moderate soil moisture stress during tuber set (tuberization) results in significantly lower tuber numbers. Tuberization begins when potato plants are 6-8" (15-20 cm) high (Figure 1.3-1). Maintaining soil moisture at or above 65% of the available soil water (ASW) capacity, when the plants are between 6" (15 cm) high results in a high tuber set. By the time the potato plants begin to flower, stem numbers and soil moisture have established tuber number.

Plant spacing

Increasing the in-row population results in more stems and tubers per acre (hectare). This increases the competition for nutrients, moisture and sunlight resulting in smaller tubers. Growers who strive for high yields of small tubers should plant potatoes 6" (15 cm) apart. Yields of most varieties increase as in-row population increase. Increasing plant populations also increases the demand for fertilizer and water.

Table 5.0-1 Specific recommendations for the planting of small potatoes for mid- and late-season (storage) markets.

Controllable input	Specific recommendations	Comments
Variety		Early, naturally tend to set high
Seed type	Whole, 2-4 oz (60-120 g) seed preferred.	Seed tubers can be cut if whole seed is not available. Seed pieces cut from large seed tubers should be a minimum of 2 oz (60 g), or larger.
Seed tuber size	2 to 4 oz (60 to 120 g)	Small seed tubers or small pieces result in low stem numbers per plant and therefore low tuber numbers. Small seed pieces (<1.5 oz or 40 g) produce weak, unproductive plants and should be culled.
Seed warming	Warm seed for two or more weeks prior to planting to ensure that the eyes are starting to peep.	If the weather turns bad near the scheduled planting date, seed tubers can be cooled to prevent excessive sprout growth prior to planting.
Green sprouting or chitting. (Widely used in Europe, primarily for the early market, but will also increase tuber numbers per plant.)	Eight weeks before planting seed tubers are warmed to 68°F (20°C). Seed tubers are then placed in flats or mesh bags in light for two weeks prior to planting. Plants emerge early and set heavy.	Tubers, which are green sprouted outside must be protected from evening frosts with covers or by moving indoors at night. Seed tubers exposed to warmth and sunlight will start to sprout, however the sprouts will remain short as the light prevents sprout elongation. Green sprouted seed develops earlier and may be useful for production of early season small potatoes.
Planting date and vine killing	Plant as early as possible for early and mid-season small tubers. The planting date for small potatoes going into storage should be delayed until late May or early June. Local experience will dictate best "days to harvest" period, however small potatoes should be ready for harvest between 70 and 90 days, depending on variety, tuber set, fertility and moisture. High tuber populations will delay sizing.	Planting of potatoes for storage should be delayed because of the risks of killing vines very early. If a crop is planted early, tubers will be of (small) marketable size by mid to late July. If they are vine killed (chemically or mechanically) at that time, the small tubers may overheat in the soil. This can cause excessive moisture loss from the tubers and make them vulnerable to disease at harvest. When tops are killed early, soils do not dry well after late summer rains, again making the tubers prone to disease.
Fertility	Pre-plant application of fertilizers should be based on soil test results.	Tissue tests should be taken to assess nitrogen status during the growing season and nitrogen should be added through the irrigation water as required. Potatoes deficient in nitrogen are susceptible to early blight and will die prematurely.
In-row and inter-row spacing	Space seed tubers or pieces 6" (15 cm) apart in the row. Rows should be 35" (90 cm) apart.	Growers who wish to produce small tubers for the early market in July when prices are high can space seed pieces farther apart in the row. Potatoes for later markets should be spaced at the recommended distances.
Irrigation	Irrigation is strongly recommended for this intensive production. Maintain soil moisture above 65% of the available soil water (ASW) capacity from the time of emergence to harvest.	Dryness at any time during tuberization will reduce tuber numbers dramatically. Small tubers can be grown without irrigation where there is an adequate supply of natural water. However, yields and quality will be consistently higher in most areas and years when supplemental water is applied.

6 Seed Potato Production Management

The Prairie Provinces annually produce more than 25,000 acres (10,000 ha) of certified seed potatoes. Seed potato production for commercial planting is primarily at the Elite 3, Elite 4 and Foundation classes (refer to table 6.1-1 for more information about the Seed Potato Production Pyramid).

The range of potato varieties produced in the Prairie Provinces varies with the demand and ultimate use of the raw potato. Most of the fields entered for certification are for the production of processing potatoes. Russet Burbank and Shepody are the main French fry processing varieties, while Atlantic, Norvalley and Snowden are the main chip processing varieties. The majority of these seed potatoes are grown under contract with potato processing companies. Other varieties are produced for the production of table potatoes. These include red skin, white skin and yellow flesh varieties. In addition, several novelty varieties are produced for the home garden trade.

This chapter was written to provide general information about seed potato certification in Canada. Any persons wanting more detailed information should contact the Canadian Food Inspection Agency (CFIA) local office or the CFIA website (www.cfia-acia.agr.ca).

6.1 Seed Potato Act and Regulations (D. Kirkham)

In Canada, the inspection and certification of seed potatoes is governed by legislation contained in *Seeds Act and Part II of the Seeds Regulations*. A copy of the Act and Regulations can be obtained at the CFIA website.

The seed potato regulations define seed potatoes as: "potato tubers certified pursuant to Part II of the Seeds Regulations of the Seeds Act for reproduction purposes". Seed potatoes must, therefore, meet the standards set out by these regulations. Potato tubers that do not meet the seed potato standards do not qualify as seed potatoes and are defined as non-certified potatoes or table stock potatoes. Seed potatoes, which have been transported without official tags or a bulk-movement certificate, are also defined as non-certified potatoes (i.e. seed potatoes require an official label or documentation).

The Canadian Food Inspection Agency administers the *Seeds Act and Part II of the Seeds Regulations* and ensures that a uniform standard is applied across the country. CFIA headquarters in Nepean, Ontario, assumes the main administrative role for developing new policies and regulatory amendments in consultation with a national

seed potato industry stakeholders committee. The Operations directorate of CFIA is responsible for seed inspections and issuing certification numbers and phytosanitary certificates.

Role of CFIA Officers and Inspectors

1. To approve or reject grower applications for crop inspection.
2. To inspect and verify the cleaning and disinfecting of equipment and storage used in seed potato production.
3. To inspect grower crops and to record and report the inspection results.
4. To pass, downgrade or reject the certification of fields entered for inspection.
5. To issue Growing Crop Certificates to fields passing inspection.
6. To issue Rejection Notices to fields failing to pass field inspection.
7. To revoke certification on crops which fail to continue to meet the certification requirements.
8. To inspect and verify that seed potatoes have been graded prior to shipment.
9. To issue official tags and bulk-movement certificates on seed being shipped.
10. To carry out tuber inspections when a request for re-inspection of a lot has been received.
11. To perform post-harvest inspections of winter grow out plots under disease evaluation
12. To accredit qualifying laboratory testing for seed potatoes.

Responsibilities of the seed potato growers

1. To apply for inspection on the official form.
2. To ensure that all equipment and storage facilities are cleaned and disinfected before being used in the production and storage of seed potatoes.
3. To ensure that only eligible seed potatoes are planted on the seed farm.
4. To ensure the crop is protected from varietal mixture and disease contamination.
5. To ensure the growing crop is well managed.
6. To rogue diseased and off-type plants from seed fields.
7. To ensure the harvested crop is stored in a manner that prevents varietal mixture, contamination by disease, loss of identity, and tuber deterioration.
8. To grade the seed potato tubers to regulatory quality standards and the prescribed size requirements prior to shipping.
9. To correctly label all seed potatoes sold using official tags or bulk-movement certificates.
10. To keep field rotation, varietal history, production & storage figures and sales records to document product activity.

Seed Potato Production Pyramid

Seed potato production in Canada uses a limited generation system, which means that seed passing inspection must advance to a lower class with each generation of production. A seed crop for each production generation cannot be maintained at a specific class or move to a higher class.

Nuclear seed is at the top of the seed potato production pyramid is Nuclear Seed. Nuclear seed must be produced from disease free parent stock in a protected environment (a growth room, greenhouse or screenhouse). The parent stock has been extensively tested to confirm the absence of potato pathogens. Nuclear stock production is subjected to a series of laboratory tests to confirm freedom from certain potato pathogens. These pathogens include: potato virus X (PVX), potato virus S (PVS), potato virus M (PVM), potato virus A (PVA), potato mosaic virus (PVY), potato leaf roll virus (PLRV), potato spindle tuber viroid (PSTV), and bacterial ring rot (BRR).

In the field, seed can be increased for seven years. There are therefore seven sequential classes of seed potatoes in the Canadian Seed Potato Certification system (Table 6.1-1). Each class has a defined tolerance level for the presence of certain diseases and foreign varieties. All classes must be completely free of spindle tuber and bacterial ring rot. The tolerance levels for the other diseases increase slightly with each class produced. Therefore, the class designation describes a precise seed quality based on parentage and the amount of disease detected in the growing crop. Parallel to the schedule of classes is a field generation designation (Table 6.1-1). Contrary to the class designation, the field generation does not involve disease tolerance levels and is not a quality designator. Generation is a term that identifies only the number of years that the seed has been grown in the field or the number of field production generations after Nuclear Seed.

Table 6.1-1 Seed Potato Production Pyramid.

<u>Class</u>		<u>Field generation</u>
Pre-elite	-	1st Generation Seed
Elite 1	-	2nd Generation Seed
Elite 2	-	3rd Generation Seed
Elite 3	-	4th Generation Seed
Elite 4	-	5th Generation Seed
Foundation	-	6th Generation Seed
Certified	-	7th Generation Seed

Application to become a new seed grower

Anyone interested in becoming a seed potato grower should contact the local office of the CFIA. This should be done at least three months prior to receiving seed supplies for the spring planting.

An application made by a new grower will only be approved when cleanup and an inspector of CFIA has verified disinfection of the premises and equipment. This must be carried out before the grower can receive seed potatoes. A new applicant should also be aware that land used for seed potato production must not have been in potato production during the previous two years.

Application for crop inspection

Applications for field inspection should be made on forms supplied by CFIA. The completed application, payment of assessed fees and other required information should be delivered to the address given in the application package for all interested seed potato growers. The application deadline for seed potatoes is June 15 of the current crop year. The following information must be provided for each potato field planted:

1. Variety
2. Hectares
3. Seed Potato Class and certification number
4. Weight planted (in cwt or kg)
5. Location of the field
6. Previous crop grown on the field

The CFIA must be made aware of all crops planted by a seed potato grower (i.e. all crops including those not being grown for seed production must be listed on the application.)

All potato fields planted by a seed potato grower must be planted with eligible seed. This includes Foundation or a higher-class seed, or if U.S. seed is planted it must be of a class equivalent to Foundation or higher. Certified class or non-certified potatoes cannot be planted on a seed potato farm. US seed potatoes must be tested for Bacterial Ring Rot in a Canadian accredited laboratory to qualify for official Canadian certification status.

Additional documentation is required when the applicant has planted seed potatoes originating from another farm. This documentation is required to provide evidence of seed eligibility. It also provides evidence of seed origin and of the quantity of seed planted. The necessary documentation includes:

1. An official tag from one container of those potatoes purchased in containers (The remainder of the tags from bagged seed must be retained by the applicant for inspection by the inspector).
2. A copy of the bulk-movement certificate in the case of seed potatoes purchased in bulk.
3. A copy of a nuclear stock certificate in cases where nuclear stock is planted.
4. An Import Permit from CFIA headquarters and a Phytosanitary certificate from the USA are necessary to import seed potatoes. In addition, for certification eligibility a Bacterial Ring Rot test

from an accredited Canadian laboratory is required and a North American Seed Potato Health certificate from the state of origin is recommended to determine class eligibility of the seed potatoes in the Canadian system.

A map of the exact location of each field should also be included with the application. The map should include as much information as possible about each field (such as landmarks, nearby commercial potato fields, and buildings on the property). Growers should also identify the access route to each field.

Conditions of Inspection

The following conditions may result in the rejection of a grower's application:

1. The total area entered for certification is less than 0.25 acres (or 0.1 ha) in size.
2. Bacterial ring rot infected potatoes were found in the field, buildings, or on equipment used by the grower.
3. An inspector did not verify cleanup and disinfection of the buildings and equipment.
4. Non-eligible potatoes have been planted on the farm. The following are identified to be non-eligible potatoes:
 - a) Certified class seed potatoes
 - b) US seed potatoes that do not have any Canadian class equivalency.
 - c) Non-certified (table) potatoes
 - d) Seed potatoes exposed to contamination by ring rot.
5. The crop is growing in a field where there has been an occurrence of bacterial ring rot. (Unless the inspector has verified that the field has been free of potatoes, including volunteers for the previous two years.)
6. The certification fee has not been paid.

An inspector may refuse to inspect a specific crop or field where:

1. A condition exists that interferes with an inspector's ability to conduct a visual inspection of the crop. This can include poor growth, lack of vigour or leaf injury brought about by late planting, lack of cultivation, the existence of excessive weeds, weather conditions, soil conditions, chemical injury, insect damage or pesticide damage.
2. The field is located within 197 feet (60 metres) of another field that has visible symptoms of a virus disease that exceeds the tolerance limits for the class of seed being produced.
3. The distance between adjacent seed potato fields is less than one blank row.
4. The crop is growing in a field where non-certified potatoes were planted in the previous two years.

The seed producer may be requested to submit all the official tags from the containers of seed potatoes that were purchased.

Potato fields entered for certification are inspected two or three times during the growing season by a CFIA inspector, prior to top-kill. At the time of inspection, the inspector will decide whether the crop meets the standards for the class to be produced. Before the inspection occurs, the seed grower should ensure that the seed fields are rogued of diseased plants. Potato fields that are not entered for inspection but are being grown by the seed grower for non-seed use may also be subject to a field inspection.

Disease Standards for Certified Seed Potatoes

The following are the final inspection tolerance levels for Elite 1, Elite 2, Elite 3, Elite 4, Foundation and Certified class seed:

Table 6.1-2 Disease standards for Certified Seed Potatoes

DISEASE & VARIETAL MIXTURE	E1	E2	E3	E4	FD	CERT
PSTV	0.0	0.0	0.0	0.0	0.0	0.0
RING ROT	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ALL VIRUSES	0.0	0.1	0.2	0.3	0.5	2.0
TOTAL BLACKLEG & WILTS	0.1	0.2	0.3	0.5	1.0	2.0
VARIETAL MIXTURES	0.0	0.0	0.0	0.1	0.2	0.5

Nuclear and Pre-Elite class seed have a 0.0% tolerance for all diseases on final inspection.

Nuclear and Pre-Elite class seed have a 0.0% tolerance for all diseases on final inspection.

Finally, a random tuber sample of Elite 2, Elite 3, Elite 4 and Foundation seed lots are subjected to a laboratory test and must be found NOT POSITIVE for the presence of *Clavibacter michiganensis subsp sepedonicus* (Bacterial Ring Rot) before it can be sold (Also see 6.4 *Post Harvest Testing* and Table 6.4-1).

Where an inspector has inspected crops in a seed potato farm and finds they meet the standards set out in the regulations, a "Growing Crop Certificate" will be issued to the grower. The Growing Crop Certificate specifies the following for each crop:

1. Class and variety,
2. Number of hectares that passed inspection, and
3. Certificate number.

Crop certificates will not be issued or may be revoked in the following cases:

1. An inspector learns that any one of the lots are infected with *Clavibacter michiganensis subsp sepedonicus* (Bacterial Ring Rot).

2. An inspector has determined that the crop does not meet the standards for any class of seed.
3. An inspector has determined that the crop has been infected with the potato spindle tuber viroid.
4. The crop has been treated with or exposed to a sprout inhibitor.
5. Any one of the lots has come into contact with used, shared or custom equipment that was used in the harvesting, storing or grading of a lot that was infected with ring rot bacteria.
6. The seed potatoes have lost their identity.
7. The seed has lost its ability to propagate.
8. The inspector determines that non-certified potatoes from another farm are stored with the certified seed potatoes or that the certified seed potatoes were stored, graded or handled with common equipment.

6.2 Early Generation Seed Production

This section to be included in future manual update.

6.3 Seed Potato Production Practices (Dennis Lidgett)

Many of the practices used in seed production are similar to those used in commercial production. Only those practices that are specific to seed production are discussed in this section. The reader should read the commercial production section of this manual to obtain a more complete understanding of potato production and storage practices.

6.3.1 Seed Selection, Cutting, Planting, Fertility and Weed Control

Seed Selection and Handling

A potato crop is only as good as the seed. When purchasing seed, ensure the supplier has a reputation of delivering a quality product. Also, check that the growing area has a history of producing quality seed. A visit to prospective seed suppliers both during the growing season and once the crop is in storage will assist to ensure quality. Before buying any seed for re-certification, the grower should be satisfied that the seed is going to have a good chance of passing the certification inspections. It is generally fruitless to plant a seed lot having even a low incidence of disease with the expectation that the diseased plants can be removed through roguing. Check the results of field and storage inspections and insist on Post Harvest test results before agreeing to purchase seed. See section 6.4 *Post Harvest Testing* for more information. When negotiating purchase of a seed lot, determine the method of delivery, date of delivery, desired tuber size distribution, tuber temperature and degree of sprout development.

Check the results of field and storage inspections and insist on Post Harvest test results before agreeing to purchase seed.

Inspect the seed immediately (and frequently) during delivery to ensure that it meets the agreed upon quality stipulations. The buyer should contact both the seed potato grower and CFIA within two working days after receiving the seed potatoes, if not satisfied with the quality. If a re-inspection is requested it will be carried out by a CFIA inspector within five working days after receipt of the complaint. The buyer should have seed tags and some unopened sacks (for bagged lots) or the bulk-movement certificate (for bulk lots) on hand, so that the proper information can be conveyed to the inspector when lodging a complaint.

All machinery, transport and storage surfaces that the seed will contact should be cleaned and disinfected prior to receiving new seed. Sanitation consists of cleaning and disinfecting all equipment, storage, tools and pallet boxes that contact the seed potatoes. Since most disinfectants are inactivated by soil and plant debris, it is essential that this material be removed by thoroughly cleaning the equipment and storage with a pressure washer or steam cleaner before the disinfectant is applied. The seed storage and all equipment coming in contact with the seed lot should be disinfected with a quaternary ammonium compound such as Ag-Services Incorporated General Storage Disinfectant, Bardak 2210 Disinfectant Sanitizer, or DMR-23 Disinfectant. Surfaces must remain wet for at least 10 minutes for the disinfectant to destroy disease organisms.

Restrict contact between incoming seed lots and any potatoes left over from the previous year. Cull potatoes are a particularly important potential source of disease. Avoid sharing equipment between farms; sharing seed cutting equipment is particularly risky.

Whole Versus Cut Seed (Also see 3.2.2 Whole Versus Cut Seed)

Whole seed has many advantages over cut seed, particularly in the production of seed potatoes:

- The wounds produced by cutting seed presents entry points for many disease-causing organisms
- Seed cutting equipment contaminated with a disease pathogen spreads disease both within and between seed lots
- Where the seed regulations require tuber unit planting the planting of whole seed is an acceptable alternative
- Whole seed tends to produce large numbers of relatively small tubers, which is ideal for seed production
- Whole seed generally produces a more uniform stand both in emergence percentage and in growth characteristics, which makes more efficient use of the production inputs (irrigation water, fertilizers and pesticides)
- Whole seed eliminates the equipment and labour cost of cutting.

Seed Cutting (Also see 3.2.5 Seed Cutting and 3.2.6 Determining Cut-Seed Size)

Planting (Also see 3.3 Planting Management)

Timely planting is as important in seed production as in table or processing production. Plant early and plan on an early vine kill and harvest. This will reduce the risk of introduction and spread of viral diseases by late season winged aphid. Plant the highest generation seed

lots first to minimize risk of disease. Clean all equipment between seed lots. Cup type planters are less likely to spread disease within a seed lot than pick-type planters.

Seed spacing (Also see 3.3.2 In-Row Seed Spacing)

In-row spacing is the main factor controlling tuber size. Optimum seed spacing is based on varietal characteristics and climactic conditions. Closer in-row spacing is used in seed production to maximize yield of the desirable, smaller tuber sizes. In-row spacing of 6-12" (15-30 cm) are recommended for seed production, depending on variety, irrigated or rain-fed production, area in which the potatoes are grown and other climactic conditions

Fertility (Also see 3.4.4 Fertility and Fertilizers)

Fertility requirements for seed are generally comparable to other types of production. Highly vigorous, early-generation seed may require less fertilizer for optimum yields, particularly if the crop is grown under rain-fed conditions or is going to be top-killed early.

Weed control (Also see 3.6.3 Weed Management)

Uncontrolled weed growth in seed potato fields will:

- Interfere with proper inspection and roguing
- Restrict air flow through the canopy which increases the potential for disease development
- Provide alternate hosts for diseases and insects capable of spreading disease.
- Rob the crop of fertility and moisture
- Interfere with a timely and gentle harvest

Effective weed control in seed fields can be obtained through timely tillage and the application of approved herbicides. Note that some herbicides registered for use in table and processing potatoes are not recommended in seed crops. Caution should be exercised when applying herbicides to adjacent crops. Drift of certain herbicides can be translocated to the daughter tubers. The affected tubers lack vigour and produce plants displaying symptoms of herbicide injury. Herbicide residues from previous crops can also be taken up by the seed crop producing similar results.

6.3.2 Disease Prevention, Roguing and Insect and Irrigation Management

Disease Prevention (Also see 3.6.4 Disease Management)

In seed potato production it is imperative to maintain disease within levels tolerated by the certification system (Table 6.1-2). Failure to achieve the tolerated disease levels will result in either the downgrading or rejection of specific seed lots or in certain cases the rejection of the

entire farm from certification. Bacterial ring rot is the most devastating disease since its presence will result in the rejection of the total farm.

Many disease pathogens are normally present in potato production areas. Consequently, there is a constant potential for the introduction of these pathogens into a seed crop. The seed grower must be constantly aware of the potential sources of disease introduction, the mechanisms of disease spread and the methods of preventing disease introduction. Grower reputation is built upon preventing or minimizing disease introduction and spread in the seed crop.

Preventing disease contamination of seed lots is the main objective of seed potato production. Disease contamination can occur from four sources:

1. The parent seed used to produce the crop.
2. The equipment and storage used in potato production and handling.
3. The soil used to produce the crop.
4. Insects transmitting disease from other potatoes in the crop production area.

Preventing disease contamination of seed lots is the main objective of seed potato production.

Seed Source

Many disease problems in a seed operation can be traced indirectly and sometimes directly to purchased seed. This is especially true with bacterial ring rot, although leaf roll and mosaic viruses are also frequently problems in purchased seed. Purchase seed from experienced growers who have a reputation for producing quality, disease free seed.

Equipment Contamination

Contaminated potato handling equipment is an important source of disease introduction and spread. Ring rot bacteria can contaminate equipment used in fieldwork or potato handling and potato structures through contact with diseased material. Dormant ring rot bacteria can survive several years in a desiccated state on the surfaces of equipment or storage structures. For these reasons, seed growers are discouraged from purchasing used equipment or from sharing equipment with other producers. If this type of equipment is used it must be thoroughly cleaned of dirt and debris with a high-pressure washer then disinfected under the supervision of a seed inspector. Parts with the potential to harbour disease inoculum such as the sponge or soft rubber rollers used on seed cutters, should be replaced.

When equipment is in need of a cleanup, the seed potato growers must use proper sanitation procedures and apply them rigorously. Sanitation consists of cleaning and disinfecting all equipment, storage, tools and pallet boxes that contact the seed potatoes. Since most disinfectants are inactivated by soil and plant debris, it is essential that this material be removed by thoroughly cleaning the equipment with a pressure washer or steam cleaner before the disinfectant is applied. The seed storage and all equipment coming in contact with the seed lot should be disinfectant with a quaternary ammonium compound such as Ag-Service Incorporated General Storage Disinfectant, Bardak 2210 Disinfectant Sanitizer, or DMR-23 Disinfectant. Surfaces must remain wet for at least 10 minutes for the disinfectant to destroy disease organisms.

Field Borne Diseases

Certain potato diseases can survive from season to season in the field. Depending on the type of pathogen, it may survive in the resting form either in the soil or in potato plant debris, or in a living form in surviving potato tubers. On occasion, diseased tubers survive the winter and grow the following spring as diseased volunteer plants. These volunteer potatoes are a source of contamination for the current season crops. Most seed potato producers practice a three to four year rotation to minimize soil disease problems. Fields with a previous history of bacterial ring rot infection should not be used for potato production for a minimum of two years, and during those two years volunteer potato plants must be eliminated.

Growing Seed Potatoes in a Commercial Production Area (Also see 3.6.2 Insect Management)

Sucking and chewing insects carry many viral diseases of potatoes. For example, aphids transmit potato leaf roll and mosaic viruses from plant to plant. Aphids become infected with the virus while feeding on diseased plants and are capable of transmitting the virus to healthy seed plants. Attempts to control aphids in the seed fields may fail to prevent disease introduction. A virus-infected aphid may feed on a potato plant leaf and introduce the virus into the plant before it succumbs to an insecticide; however, insecticides do prevent disease transmission from continuing unchecked.

Seed growers who are producing in commercial production areas with the associated greater risk of disease inoculum should attempt to isolate their seed fields from potential sources of contamination. If that option is not available, then the grower should attempt to control viruliferous (virus-infected) aphids in the source field before winged aphids migrate to seed fields, spreading virus to the seed crop. If the seed field already has virus-infected plants then the application of pesticides will help prevent spread within the field.

Planting seed with low or zero incidence of virus as reported by a post-harvest test, and limiting the number of seed generations produced in areas of commercial production will help to limit virus spread within seed crops. Roguing all infected plants as early as possible prevents in field spread by aphids.

Roguing

Planting seed with low or zero incidence of virus as reported by a post-harvest test, and limiting the number of seed generations produced in areas of commercial production will help to limit virus spread within seed crops.

The purpose of roguing is to:

- Remove plants of a variety different from that planted in the field
- Remove diseased plants that will produce diseased seed tubers or which represent inoculum sources for disease spread within the field
- Ensure the seed field passes inspection.

Although roguing is a common practice in seed potato production it is only practical when the field is contaminated with a very low incidence of an off variety or diseased plants that are easily distinguishable. When roguing, remove plants, seed piece and daughter tubers from the field.

The process of roguing requires:

- Experienced individuals, who are capable of recognizing the symptoms of the important potato diseases
- Appropriate timing
- Environmental conditions which contribute to the expression of visible disease symptoms.

In addition, roguing is costly, as the field may have to be walked several times to remove the off variety or diseased plants.

Roguing for viral diseases is best done prior to flowering and during overcast weather.

Although roguing is considered to be a valuable tool in the maintenance of seed quality, it is rarely completely effective. Only those plants that are manifesting visually recognizable symptoms can be rogued. Symptom expression can be influenced by many factors including environmental conditions and varietal characteristics. In addition, not all pathogen-infected plants (even those from seed pieces cut from the same tuber) express disease

symptoms to the same degree or at the same stage of growth. The end result is that much of the roguing is conducted to provide a visually clean field that will satisfy the seed certification specifications.

Tuber-unit planting is a tool that has been used to improve the effectiveness of the roguing process. All seed pieces cut from a single tuber are manually fed into a planting mechanism, which places them consecutively in a row. A gap is sometimes left between the seed pieces generated from different tubers. If the plants originating from any of the seed pieces cut from a single tuber express symptoms of disease, then all the seed pieces cut from the tuber are removed from the field. This ensures that all seed is removed from the field even if only one piece is manifesting symptoms of disease or has characteristics of a foreign variety. Since tuber-unit planting is slow and very labour intensive, its use is limited to small plots of high value seed. This practice was a regulatory requirement for the first and second field generations of seed. Regulatory amendments approved in May 2002, resulted in the removal of this requirement from seed regulations, due to cost, and time consideration, relative to industry benefits. However, it is considered an important management tool for seed growers, particularly when a grower has concerns for the level of virus that may be present in seed planted.

Insect Management (Also see 3.6.2 Insect Management)
Certain types of aphids and leafhoppers have the potential to both introduce and spread viral diseases within a seed crop. Controlling the populations of these insects by the application of insecticides at planting or after crop emergence will reduce, but not completely eliminate, problems with insect-borne disease. Seed growers should monitor insect populations and if possible, plan on vine killing before insect numbers increase beyond acceptable levels. Isolation and planting clean seed will also reduce the risk of insects spreading disease within the seed crop.

Irrigation (Also see 3.5 Irrigation Management)
A continuous supply of an adequate amount of moisture via timely rainfall or irrigation is crucial for maximizing yields and quality of seed potatoes. Adequate moisture at tuber set is particularly important as it encourages setting of a large number of tubers and controls or reduces the severity of common scab. Over-irrigation increases susceptibility to late blight, blackleg, powdery scab and tuber rots. The wheels on wheel-move and centre pivot irrigation systems may contribute to the transmission of some viral or bacterial diseases within the field.

6.3.3 Harvest and Storage Management

Vine Killing: (Also see 3.8.3 Vine Killing)

The purpose of vine killing in seed production is to:

- Reduce the risk of late season virus transmission by winged aphids. Early generation seed should be killed by mid August
- Stop tuber growth to obtain a desirable tuber size profile
- Promote skin set and prevent bruising. A well-developed skin resists damage during harvest, which reduces the potential for infection to enter the tuber causing rot. Vines should be killed (dead and dry) for 10 to 14 days before harvesting to achieve maximum resistance to bruising and skinning
- Allow easy separation of the vine from the tubers during harvest

Vine killing will reduce the risk of late season virus transmission by winged aphids.

Bruise prevention (See 3.8.4 Bruise Prevention)

Seed Storage (Also see 3.9 Potato Storage Management)
Growers must ensure that each class and variety of seed is kept separate through harvest, grading and storage. Bin dividers can be used to sub-divide larger bins, allowing the safe storage of multiple seed lots. The contents of each bin should be clearly labelled to avoid accidental contamination with differing varieties or generations.

Seed cannot be treated with storage-applied sprout inhibitors such as CIPC. Due to the potential for drift, seed potatoes cannot be stored in the same building as any potatoes treated with CIPC. Similarly, seed should not be stored in buildings treated with CIPC in previous years as this volatile compound is absorbed into the storage structure.

Seed should be cured at 55-60°F (13-15°C) and 95% RH with good airflow for two weeks. Once curing is completed, reduce the ventilation rate and gradually cool the pile to a final holding temperature of 37-40°F (3-5°C) with 95% RH. The condition of the pile should be checked regularly during the storage period. Restrict access to the storage to reduce the potential for introducing disease.

6.4 Post Harvest Testing (D. Lidgett)

The purpose of the post harvest test (PHT) is to preview a seed lot's disease status for the next crop year. Late season virus transmission by aphids is difficult to detect in field inspections as they seldom produce recognizable symptoms. A reliable PHT identifies if virus infections have occurred and enables the grower to determine the crop's suitability for seed purposes. The PHT is performed on a random sample of seed tubers collected by the seed grower. Sample collection is discussed later in this section.

The PHT is not part of the Canadian Seed Potato Certification program. It is an industry-administered program designed to provide a level of assurance of seed potato quality, which is not achievable through the official certification program. Participation by growers in the PHT is voluntary. The value of the PHT is underestimated, since the test is not considered a condition of certification. Nevertheless, it is suggested that all seed lots and fields should receive a PHT.

The Post Harvest Test (PHT) identifies if virus infections have occurred and enables the grower to determine the crop's suitability for seed purposes. All seed lots and fields should receive a PHT.

There are three options for PHT available to the industry. These include:

1. Visual inspections of the growing plants at southern grow-out sites (California, Florida or Hawaii)
2. Visual inspections at the southern grow-out site combined with a laboratory test (E.L.L.S.A.) on leaf material collected at the southern site
3. A laboratory test (E.L.L.S.A.) of leaf tissue collected from plants produced in a growth chamber or greenhouse from tuber samples received from the grower.

The reliability of the PHT results depends upon the following:

- The quality of the sample collected. See below for more details.
- The post harvest test method. Both the grow-out and laboratory PHTs are capable of detecting viruses, but only the grow-out test can detect foreign varieties. The grow-out test is based on a visual assessment of disease symptoms. Expression of visual symptoms is subject to many external factors (i.e. growing environment and variety), which limits reliability. The laboratory test (E.L.L.S.A.) is more reliable at quantifying virus levels because it is

not affected by external factors. Certain varieties such as Shepody and Russet Norkotah normally mask the field symptoms of mosaic. A laboratory PHT for PVY should be a standard practice for these cultivars.

Seed potato tubers for Post Harvest Testing (PHT) and for BRR testing must be selected at random to provide an unbiased sample that is representative of the whole field or lot. To ensure the samples submitted for testing truly represent the seed crop, it is suggested that seed growers collect a field sample of about 1000 tubers from each field. A test sample can then be randomly collected from the field sample.

The most efficient method of collecting a representative tuber sample from the crop is to collect the field sample during the harvest operation when all tubers are equally accessible. To ensure a representative sample is collected, one farm staff member should be given the training and responsibility for collecting the tubers. The sample collector should be instructed to collect a uniform number of suitably sized tubers (1 to 2 ounces (30-60 g) from every load delivered to the storage. The number of tubers collected per truck arriving at the storage will depend on the size of the field being harvested.

When the harvest of the field is complete, the field-samples should be bagged, labelled (inside and outside the bag), and placed into proper storage for safekeeping. This field sample will be later sub-sampled for the individual tests.

Four hundred (400) suitably sized tubers are required for most post harvest tests. These samples are randomly collected from the field-samples. It is suggested that the remaining portion of the field-sample be held in the storage as long as possible. This material may be useful if for testing for the presence of genetically modified organism (GMO) or BRR.

Four hundred (400) 1-2 oz (30-60 g) tubers are required for the grow-out PHT. The total weight of the sample should not exceed 50 lbs (22.7 kg). Note: Samples containing tubers in excess of 3" (7.6 cm) in diameter may be rejected for the grow-out PHT. All samples should be packed in new bags and labelled twice (inside and outside) with a tear proof label providing the following information:

- The grower's name
- The Variety
- The Class
- The Certification Number for current production year
- Grower field numbers.

Tubers submitted for the laboratory PHT or BRR test could be any size since only portions of the tubers are sent to the laboratory.

BRR Testing

The current regulatory requirement for testing for *Clavibacter michiganensis* subsp. *sepedonicus*, the causal bacteria of Ring Rot, is that all certified seed potato lots except for Pre-Elite, Elite I, and Certified

classes, that are sold by a farm unit, must be tested. Contact the Canadian Food Inspection Agency (CFIA) for a list of BRR accredited laboratories.

The size of the BRR test sample required is based on the number of hectares that were entered for certification (Table 6.4-1). The following table identifies the number of tubers required for the test according to the field size.

Table 6.4-1 Field sample size for BRR testing.

TOTAL SIZE OF SEED POTATO FIELD	NUMBER OF TUBERS
larger than 1.000 hectare	400 tubers
between 0.500 and 1.000 hectare	200 tubers
between 0.250 and 0.499 hectares	100 tubers
between 0.025 and 0.249 hectares	50 tubers
less than 0.025 hectares	1 tuber each from 1% of number of plants harvested (minimum of 5 tubers maximum 50)

A note of caution: A negative BRR test is not a guarantee of freedom from ring rot and diligence is required when purchasing seed, since the producing farm's history with the disease is sometime more important than the results of the laboratory test.

6.5 Seed Grading and Marketing (D. Lidgett)

Make every effort to prevent bruising (see section 3.8.4 Bruise Prevention).

Seed potatoes should be sized to meet the market requirements. The standard method of sizing seed potatoes is based on weight. Tubers can also be graded by dimension. When sizing by dimension, screen sizes appropriate for each variety must be used.

All seed potato classes are subject to the same tuber standards (i.e. there is only one quality grade for Canada Seed Potatoes). The quality standards provide a tolerance for symptoms of disease, damaged tubers and varietal mixtures that could affect the quality of the seed. Tolerance for disease and defect in the graded stock is defined by the tuber standards [sections 48.1 (2) to (10)] in the seed potato regulation, which are summarized in Table 6.5-1.

Table 6.5-1 Seed potato grade tolerances.

Disease or Defect	Tolerance (% by count)	
	At shipping	At destination
Soft rot or wet breakdown	0.10%	0.50%
Dry rot, including late blight	1.00%	1.00%
Scab or Rhizoctonia light	10.00%	10.00%
Scab or Rhizoctonia - moderate	5.00%	5.00%
Stem-end discolouration due: to vine killing, frost, heat, or drought with a penetration from 6 - 13 millimetres.	4.00%	4.00%
Tubers malformed or externally damaged.	2.00%	3.00%

In addition, the tolerance for foreign varieties is as follows:

- Elite 3 or Elite 4 classes of seed - none
- Foundation class of seed - 0.05%
- Certified class of seed - 0.10%

In any lot of graded seed potatoes, at least 98% of the tubers shall be firm and well shaped.

Growers are encouraged to take samples of the graded stock regularly during the grading operation to ensure the grade requirements are being met. Where problems are identified, appropriate adjustments should be made at the grading line. These may include adding additional staff or reducing the speed of the conveyers.

Seed potatoes may be packed or shipped in a variety of container sizes, including the normal jute bag and bulk containers. Bagged seed potatoes must be labelled with an official tag that identifies the variety, class and certification number of the seed lot being shipped. The following tag colours identify the respective seed classes:

- Orange tags identify the Elite Classes of seed
- White tags identify the Foundation Class of seed
- Blue tags identify the Certified Class of seed

In the case of bulk loads, the regulations require loads to be accompanied by a bulk-movement certificate. Growers are responsible for the safe storage and correct use of official labels and to ensure the seed is correctly labelled.

7.0 Colour Plates

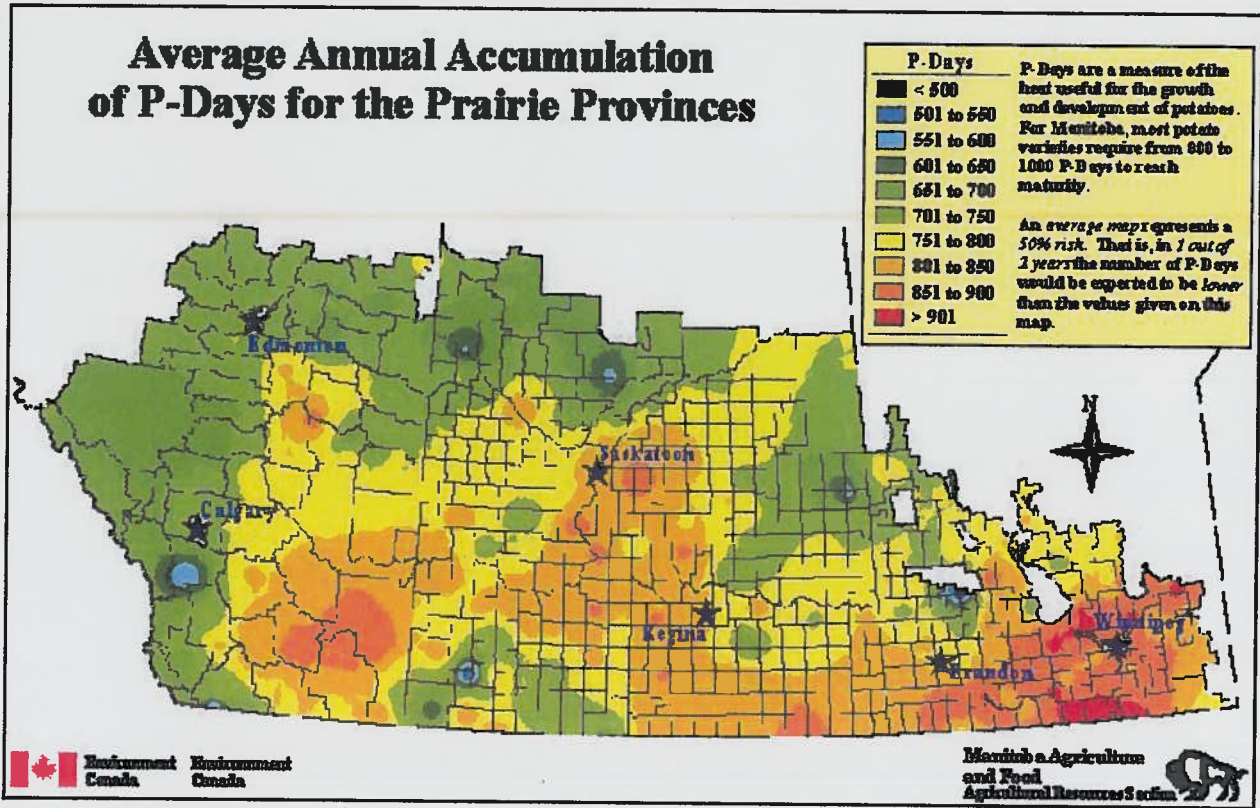


Plate 1. Average annual Physiological Days (P-Days) for the Prairie Provinces. (Courtesy of Manitoba Agriculture and Food)

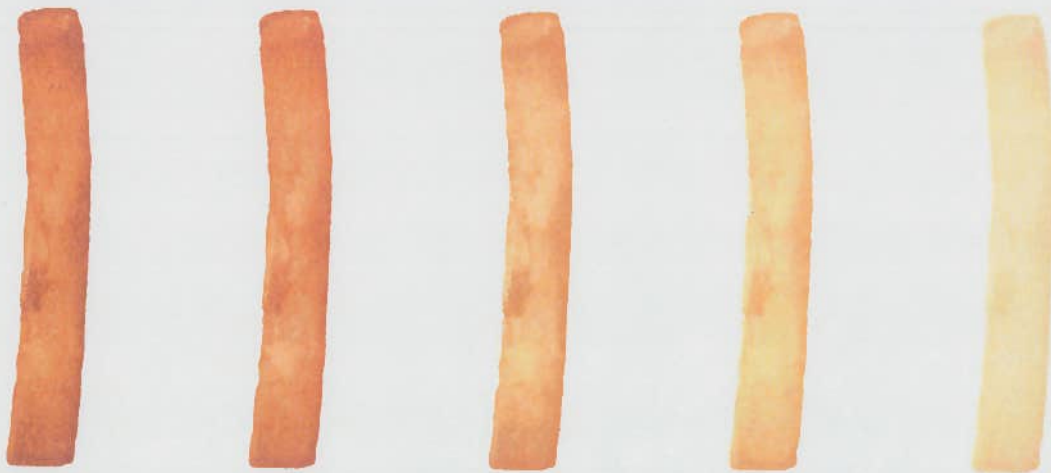


Plate 2. USDA French fry color chart.



Plate 3. Colorado potato beetle adult. (Courtesy of C. Schaupmeyer)



Plate 4. Colorado potato beetle egg mass. (Courtesy of C. Schaupmeyer)



Plate 5. Colorado potato beetle larvae. (Courtesy of C. Schaupmeyer)



Plate 6. Potato flea beetle. (Courtesy of Agriculture and Agri-Food Canada)



Plate 7. Winged aphid. (Courtesy of Agriculture and Agri-Food Canada)

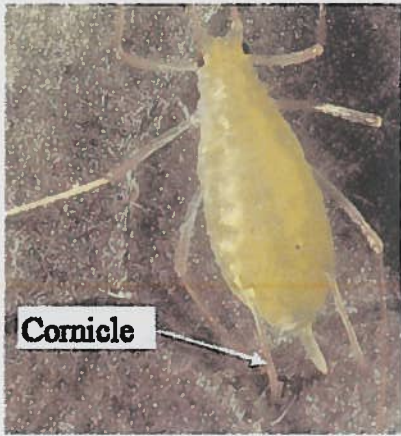


Plate 8. Aphid nymph with cornicles.
(Courtesy of Agriculture and Agri-Food Canada)



Plate 9. Leafhopper adult. (Courtesy of North Dakota State University)



Plate 10. Leafhopper nymph on left. (Courtesy of North Dakota State University)



Plate 11: Wireworm larvae. (Courtesy of C. Schaupmeyer)



Plate 12. Internal symptoms of bacterial ring rot.
(Courtesy of Manitoba Agriculture and Food)



Plate 13: External and internal symptoms of bacterial soft rot. (Courtesy of Manitoba Agriculture and Food)



Plate 14. Blackleg. (Courtesy of P. Bains, Alberta Agriculture, Food & Rural Development)



Plate 15. Common scab. (Courtesy of J. Thompson, University of Saskatchewan)



Plate 16. Early blight leaf lesion. (Courtesy of C. Schaupmeyer)



Plate 17. Fusarium dry rot. (Courtesy of P. Bains, Alberta Agriculture, Food and Rural Development)



Plate 18. Late blight leaf lesion. (Courtesy of R. Howard, Alberta Agriculture, Food and Rural Development)



Plate 19. Late blight stem lesion. (Courtesy of R. Howard, Alberta Agriculture, Food and Rural Development)



Plate 20. Late blight tuber lesion. (Courtesy of B. Geisel, Gaia Consulting Ltd.)



Plate 21. Pythium leak. (Courtesy of Manitoba Agriculture and Food)



Plate 22. Pink rot. (Courtesy of Manitoba Agriculture and Food)

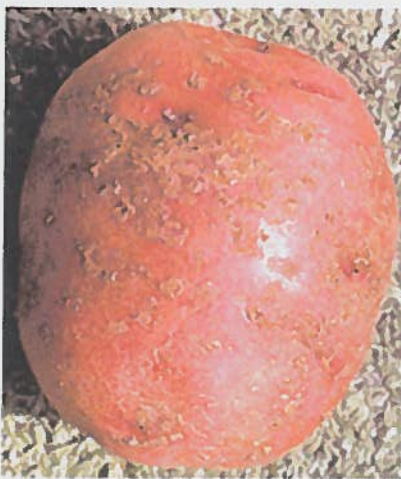


Plate 23. Powdery scab. (Courtesy of J. Thompson, University of Saskatchewan)



Plate 24. *Rhizoctonia* stem canker. (Courtesy of P. Bains, Alberta Agriculture, Food and Rural Development)



Plate 25. Silver Scurf (Courtesy of R. Howard, Agriculture and Agri-Food Canada)



Plate 26. Potato leaf roll virus (PLRV) symptoms. (Courtesy of R. Singh, Agriculture and Agri-Food Canada)



Plate 27. Net necrosis in tuber caused by PLRV. (Courtesy R.P. Singh, Agriculture and Agri-Food Canada)



Plate 28. Potato virus Y (PVY) infected plant. (Courtesy of D. Lidgett, Manitoba Seed Potato Grower's Association)



Plate 29. Potato mop top virus chevron. (Courtesy of Scottish Agricultural Science Agency)

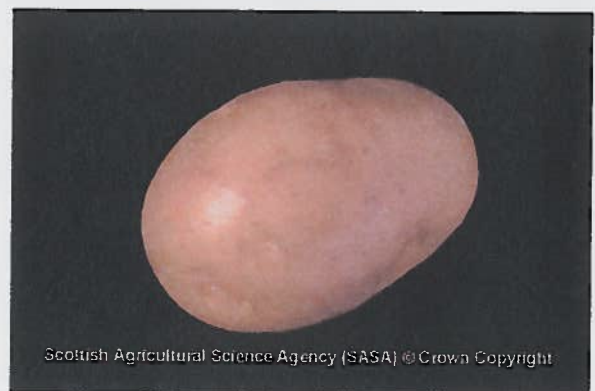


Plate 30. Potato mop top virus external tuber symptoms. (Courtesy of Scottish Agricultural Science Agency)

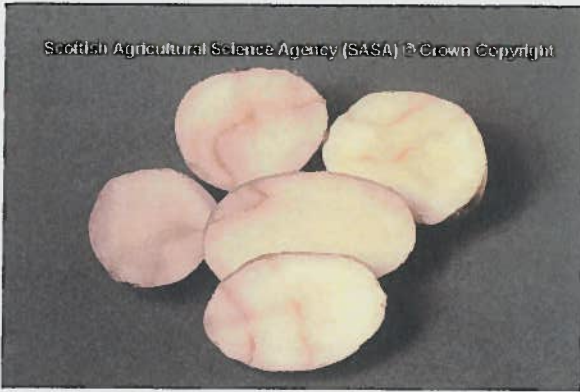


Plate 31. Potato mop top virus internal tuber symptoms. (Courtesy of Scottish Agricultural Science Agency)

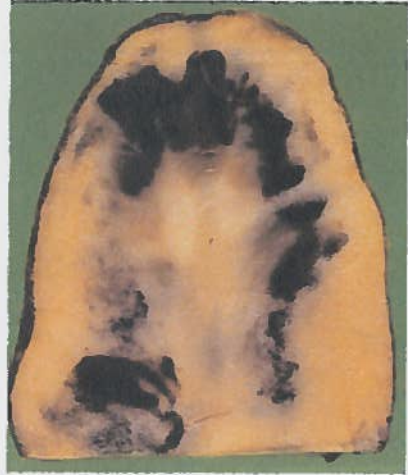


Plate 32. Blackheart internal tuber symptoms. (Courtesy of Manitoba Agriculture and Food)

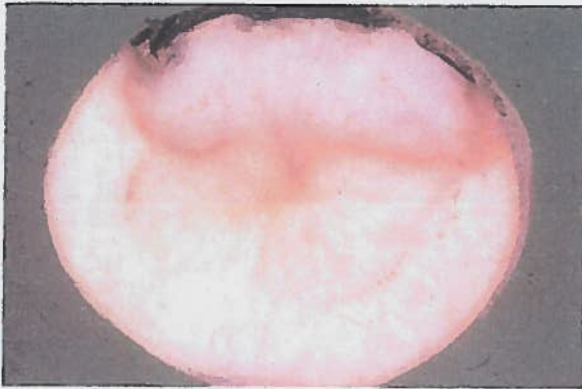


Plate 33. Low temperature injury of tuber. (Courtesy of Manitoba Agriculture and Food)