


Crop Diagnostic Handbook

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Saskatchewan

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Crops Extension Specialist Team

Over the years, the Crops Extension Specialists have committed themselves to the development of the Crop Diagnostic Handbook, shaping it into its current form. This achievement has been a collaborative effort, involving not only our dedicated team but also specialists from the Crops and Irrigation Branch and external partners, including various commodity groups. The vision we hold for the Crop Diagnostic Handbook is clearly reflected in its overarching goals and purpose.

CDS Handbook Goal and Purpose

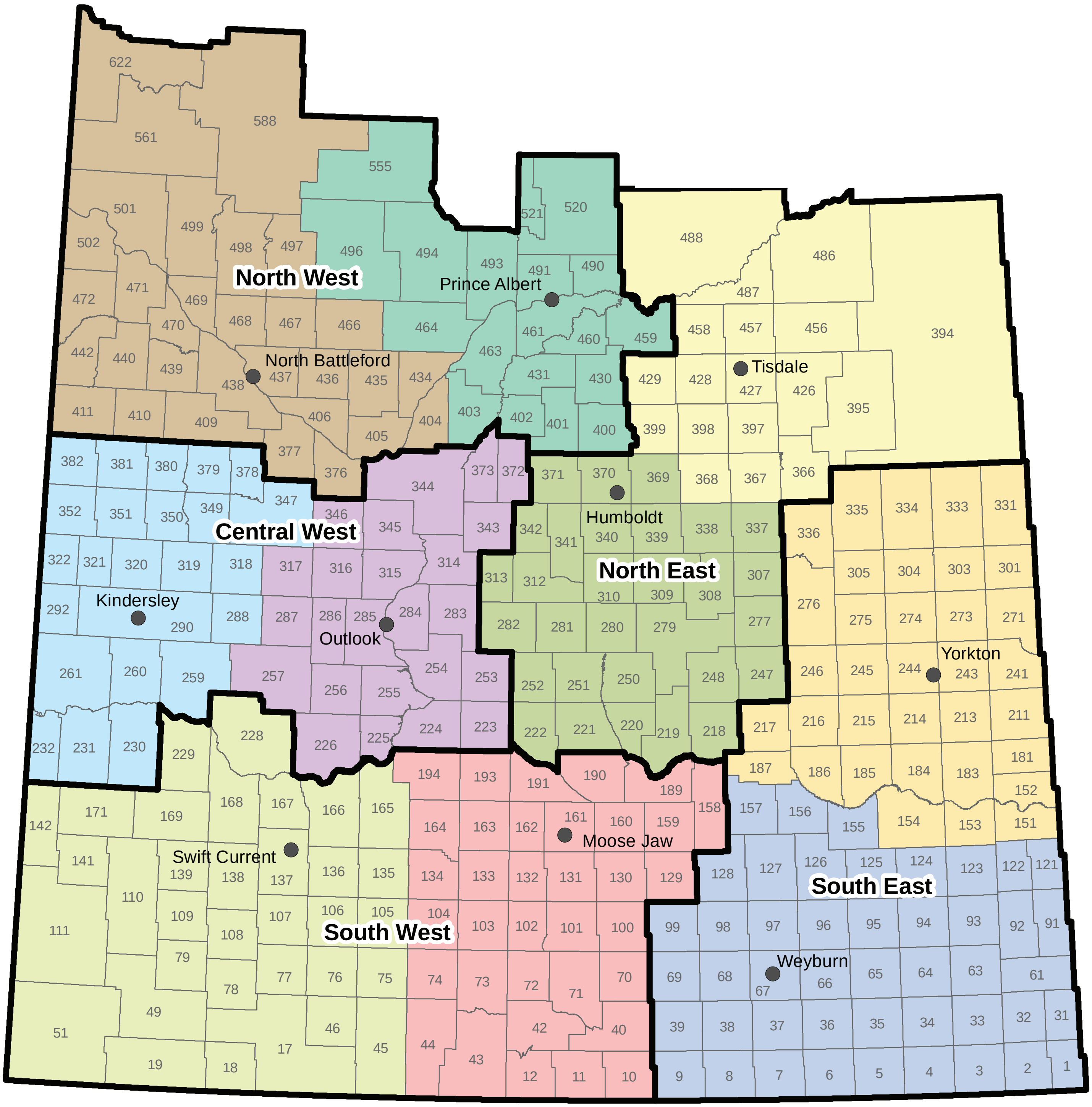
The Crop Diagnostic Handbook is a valuable resource for producers and agrologists to use in Saskatchewan. The handbook includes basic agronomic information for scouting and diagnostic purposes, symptomology and identification of diseases and insects, environmental impacts, and information for agronomic and grain management decisions made at harvest.

Our role is to offer valuable extension materials and information, such as the CDS Handbook, to producers and agronomists in Saskatchewan. Below is a brief outline of our goals as Crops Extension Specialists in our daily work.

- Offer producers and agronomists unbiased agronomic advice and timely feedback specific to their operation or their client's needs.
- Offer extension services to producers that help them achieve optimal yields using research-based agronomic practices and technology.
- Monitor pest populations, growing conditions and crop development across the province to provide producers with the latest crop production information so they can assess risk and make well-informed cropping and input decisions.
- Connect researchers and the work they do directly with stake holders through extension events.

Crops Extension Specialists (CES) Area Boundaries

Humboldt	306-682-6701	Outlook	306-867-5527
Kindersley	306-463-5513	Prince Albert	306-953-2363
North Battleford	306-446-7962	Swift Current	306-778-8285
Moose Jaw	306-694-3721	Tisdale	306-878-8842
		Weyburn	306-848-2857
		Yorkton	306-786-1531



Section 1: General Agronomy

Cereals and Annual Grasses Plant Staging

To stage cereal plants, it is important to differentiate between the main stem (largest stem with the most leaves) and the tillers (at the base of leaves on the main stem).

Figure 1.1 (a) Leaf stages of cereals & annual grass weeds

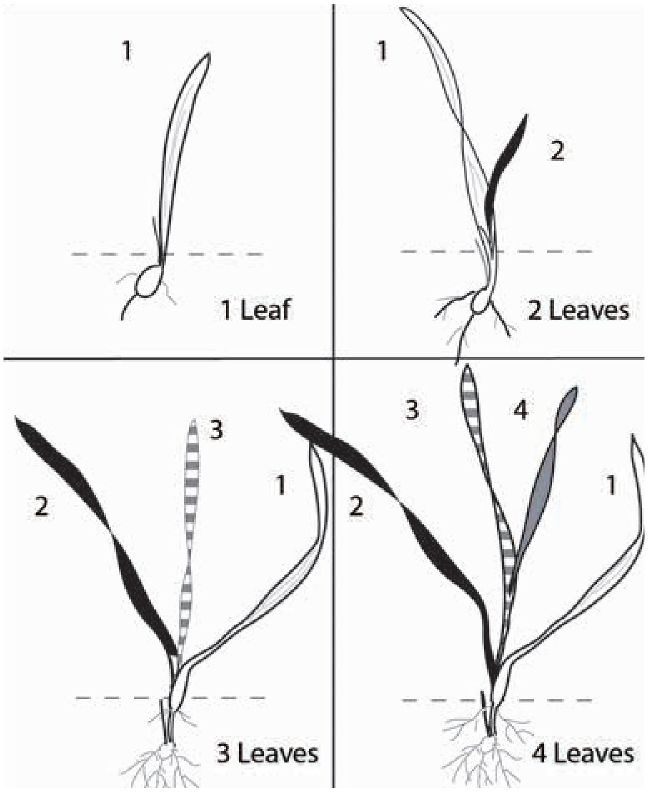
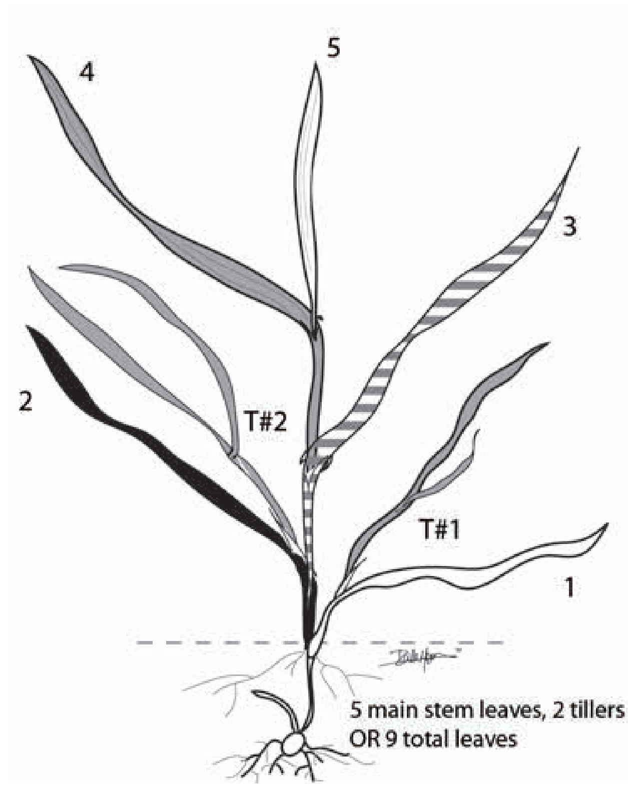


Figure 1.1(b) 5 Main stem leaves, 2 tillers or 9 total leaves



Locate the first leaf

- The first leaf is the lowest leaf with a blunt tip.
- Appears on the opposite side of the plant from the coleoptile and the coleoptilar tiller.

Locate the main shoot

- Position the plant-first leaf points to your left and fan out the leaves and tillers.
- The main shoot is the tallest shoot and has the most leaves.
- Count the leaves on the main shoot or stem. Leaves are counted when they are over one-half the length of the leaf below.

Counting tillers

- Locate the leaf sheath that encloses the base of the tiller.
- Primary tillers arise from each leaf of the main stem.
- Coleoptilar tillers arise from the coleoptilar node at the base of the plant. Coleoptilar tillers appear separate from the other tillers and are not counted when staging.

To check for jointing and stem elongation

- Remove the roots and tillers.
- Split the remaining stem in half and locate the position of the growing point or grain head.
- If three or four nodes are visible, check to see if the last leaf is the flag leaf. Cut the stem below the highest node, unwrap the stem/leaves to expose the developing head.
- If there are no leaves enclosing the head then the last leaf is the flag leaf.
- The flag leaf is the last leaf to emerge before the head emerges.
- The leaf prior to the flag leaf is called the penultimate leaf.

Note: The flag leaf is a major contributor to grain yield, and accounts for 40-75 per cent of yield, depending on crop type. Emergence of the flag leaf is important for application timing of fungicide and plant growth regulators. The penultimate leaf contributes to yield, though less than the flag leaf.

Boot stage

- Look for swelling in the stem that moves upward towards the top of the plant.
- The boot stage ends when the awns are present or if no awns then the end of the head emerges.

Note: This stage is when susceptibility to wheat midge starts. As soon as the boot splits, the crop is susceptible. The crop is no longer susceptible halfway through flowering.

Heading and flowering

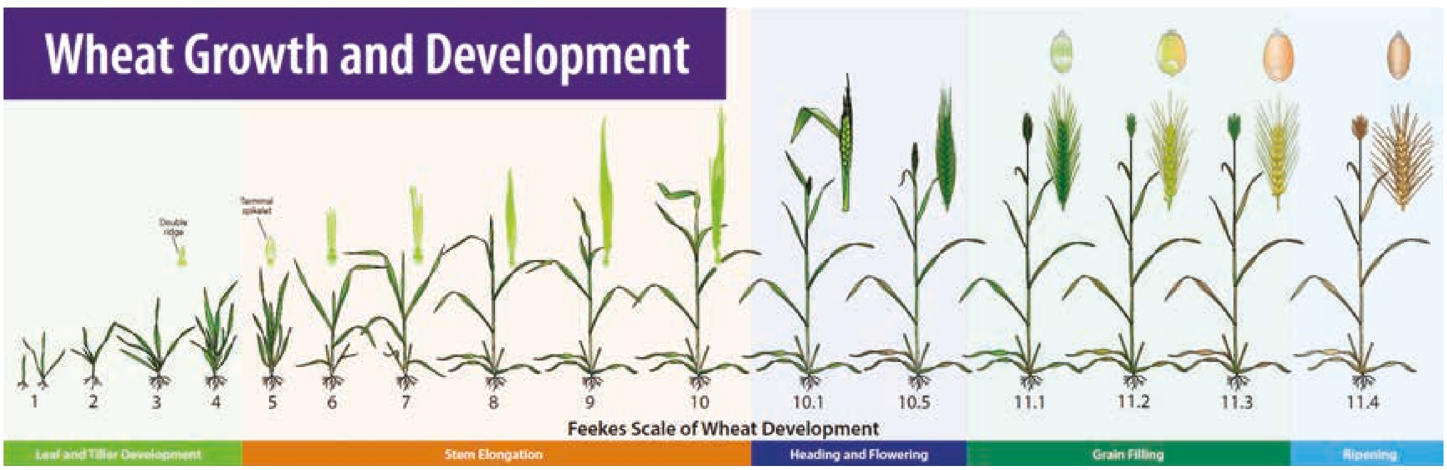
- Head emergence starts when the first spikelet is visible above the flag leaf and ends when the head is fully emerged.
- For closed-flowering cereals (mostly barley varieties), flowering occurs prior to head emergence.
- For open-flowering cereals (most wheat varieties), flowering and pollination occurs one to seven days after heading.
- Visible yellow anthers mark the end of flowering.

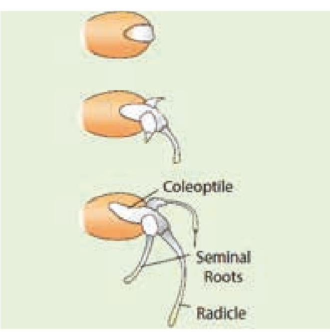
Grain development

- During the milk stage (early kernel development), a milky fluid forms that becomes more solid as the stage progresses.
- Kernel formation is completed during the dough development stage. The developing kernel is physiologically mature at the hard dough stage even though it still contains approximately 30 per cent water.

Note: Late dough stage can be determined by making a thumbnail imprint in the kernel that does not disappear.

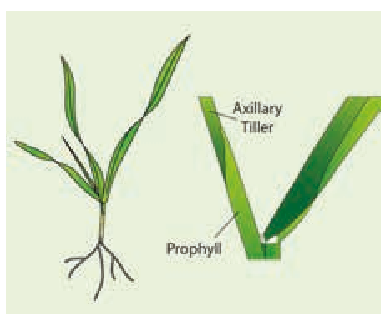
Figure 1.2 Feekes Scale of Wheat Development





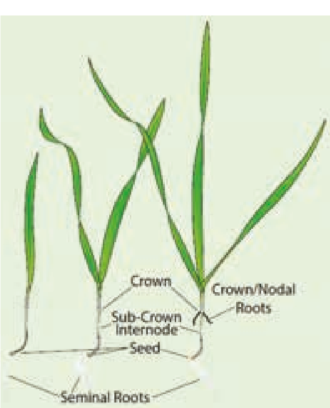
Germination

Seeds absorb water and oxygen. The radicle, seminal roots, and the coleoptile (leaflike structure enclosing the first true leaf) emerge from the seed. Temperatures between 12 and 25 C are optimal for germination.



Feekes 2

Tillering initiation. Tillers are initially encased in a protective structure called the prophyll. If there are three leaves visible, a tiller will be at the base of the first leaf. The crown root system starts to develop.

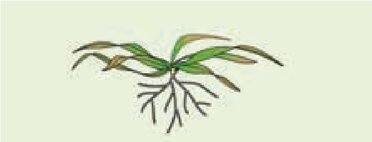


Feekes 1

Emergence. Emerging from the soil, the coleoptile stops growing when it senses light. The first true leaf emerges through the tip of the coleoptile. Three leaves fully develop before tillering initiation. The seminal rooting system expands. The crown forms between the seed and soil surface.

Feekes 3

Continued tillering. Primary tillers develop in the axils of the first four or more true leaves of the main stem. Secondary tillers may develop from the base of primary tillers. Tiller development is prioritized based on their sequential formation. The development of the crown root system increases extensively.



Winter dormancy for winter or fall varieties. This does not apply to spring varieties

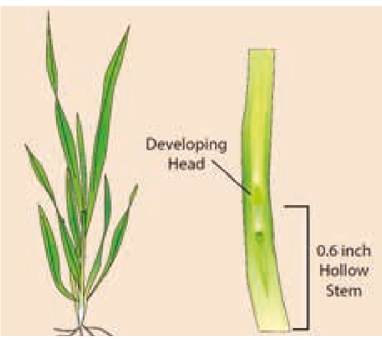
Vernalization. Gradually lowering temperatures and shortening day length induce winter hardiness in winter wheat. Vernalization requirements range from three to eight weeks of temperatures below 10 C.

Feekes 3

Completion of tillering. Once requirements are met, the growing point differentiates and the embryonic head reaches the double ridge stage. Depending on the season and planting date, some tillering occurs in the spring. Genetic potential and environmental conditions determine the number of tillers on a plant. Tillers with three or more leaves are nutritionally independent from the main stem.

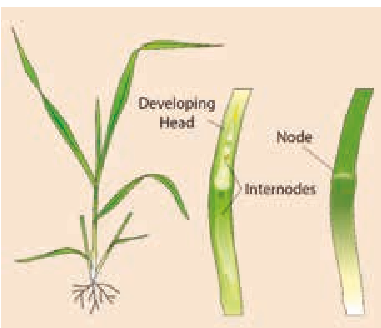
Feekes 4

Leaf sheaths lengthen (spring greenup). Leaf sheaths begin to lengthen. The pseudo-stem, a succession of leaf sheaths wrapped around each other, starts to become erect.



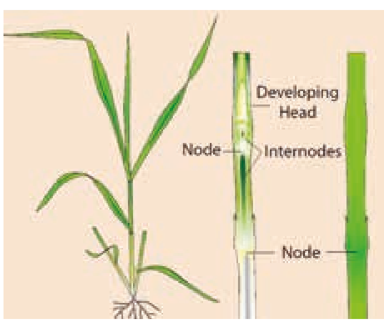
Feekes 5

Leaf sheaths strongly erect. The pseudo-stem is strongly erect and leaf sheaths are elongated. The developing head reaches the terminal spikelet stage and is pushed up into the pseudo-stem. The potential number of spikelets per head is determined at Feekes 5. The first hollow stem stage occurs when there is approximately 15 millimetres (0.6 inches) of hollow stem below the developing head.



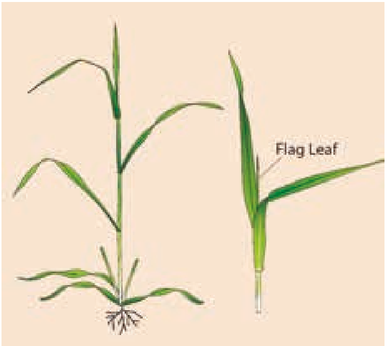
Feekes 6

First node of stem visible (jointing). The first node of the stem becomes visible as a result of internode elongation. Nodes are stacked and move up as the internodes elongate much like a telescope. Sensitivity to low temperatures increases as the developing head is pushed up by the expanding stem. Crop water demand increases to about 0.25 inch per day. Approximately 25 per cent of the total dry matter is accumulated by this stage.



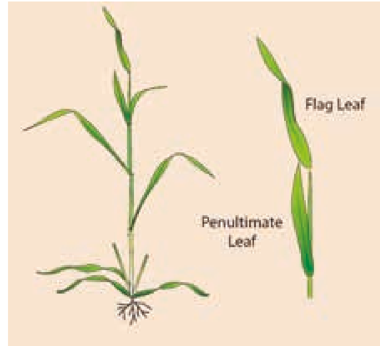
Feekes 7

Second node of stem visible. As the second node of the stem becomes visible, the next-to-last leaf is just visible. Demand for water and nutrients increases. Temperatures lower than -4 C can damage the developing head.



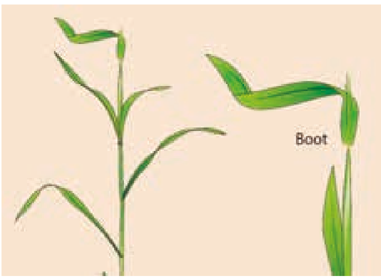
Feekes 8

Last leaf just visible. The flag leaf starts to emerge from the whorl above the third or fourth node. Strong partitioning of photosynthates to the developing head. Approximately 45 per cent of the total dry matter is accumulated by this stage.



Feekes 9

Ligule of flag leaf visible. The flag leaf is completely emerged from the whorl. Flag leaf and the next-to-last leaf (penultimate leaf) combined account for 70 to 90 per cent of the photosynthates used for grain fill and must be protected for the plant to develop to its full potential.



Feekes 10

Boot. The head is inside the leaf sheath giving it a swollen appearance. The flag leaf sheath and peduncle elongate and the developing head is pushed through the flag leaf sheath. Temperatures below -2 C may cause damage to the developing head.

Feekes 3 through 9

Double ridge. The primordia, which differentiate into spikelets, become visible after vernalization requirements are met. Floret initiation starts slightly above the middle portion of the microscopic head and moves outward. The number of florets initiated determines the potential number of kernels per head.

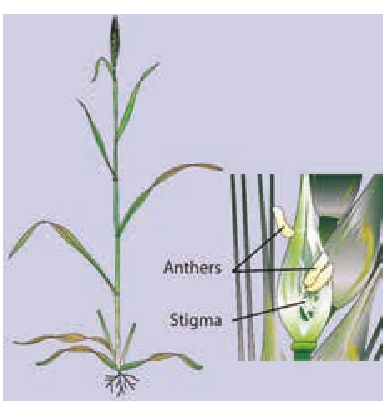
Terminal spikelet. This stage marks the completion of the spikelet initiation phase. At this stage, the number of spikelets per head has been determined. Terminal spikelet occurs at Feekes 5.

Head growth. Rapid head growth occurs in parallel with stem elongation during Feekes growth stages 6 through 9. Florets become ready for pollination and fertilization.

Head emergence. Tiller development synchronizes with the main stem, so flowering occurs almost simultaneously in the main stem and tillers, regardless of differences in tiller initiation.

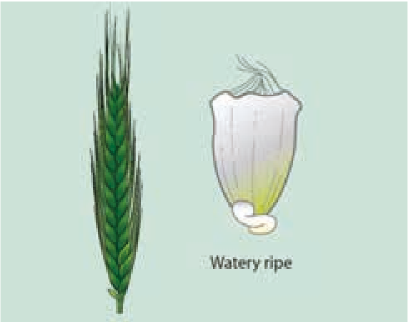
Feekes 10.1-10.5

Heading. The first heads escape through a split in the flag leaf sheath at Feekes 10.1. All heads are out of the sheath at Feekes 10.5. It usually takes three to five days for the head to fully extend above the flag leaf. Temperatures below -1 C may damage the developing head. Crop water demand can exceed 0.3 inch per day during heading through the soft dough stage.



Feekes 10.5.1-10.5.3

Flowering (anthesis). Flowering begins shortly after the head has fully emerged and lasts 3 to 5 days, starting slightly above the middle portion of the head. Feekes 10.5.2 occurs when flowering is complete at the top of the head and Feekes 10.5.3 occurs when flowering is complete at the base. The number of flowers pollinated determines the number of kernels per head. At this stage, wheat is extremely susceptible to freeze injury at temperatures below 0 C. Approximately 75 per cent of the total dry matter is accumulated by this stage.

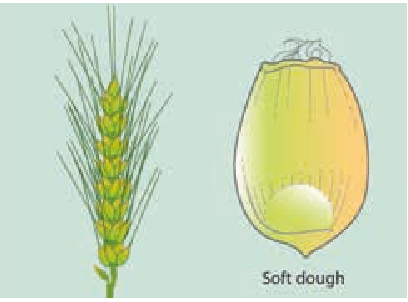


Feekes 10.5.4

Watery ripe. Establishment of kernel length about 10 days after flowering. Rapid increase in grain size, but little dry matter accumulation. A clear fluid can be squeezed from the developing kernel.

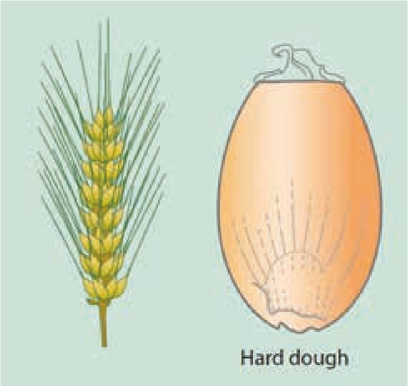
Feekes 11.1

Milky ripe (milk stage). Increase in solids content in the endosperm from photosynthates. This stage occurs 15 to 18 days after flowering. A milk-like fluid can be squeezed out of the kernels when crushed between fingers.



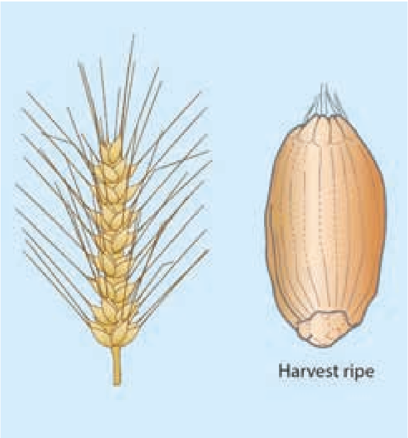
Feekes 11.2

Mealy ripe (soft dough). During the dough stage, the kernel rapidly accumulates starch and nutrients and most of its dry weight. Material squeezed out of the kernel has a doughy consistency. Green colour begins to fade and kernels are soft but dry. Maximum dry matter accumulation (100 per cent) by the end of this stage.



Feekes 11.3

Kernel hard (hard dough). Kernel moisture decreases from 40 to 30 per cent during ripening. Kernels achieve maximum dry weight and are physiologically mature. Kernels are hard and difficult to divide with thumbnail.

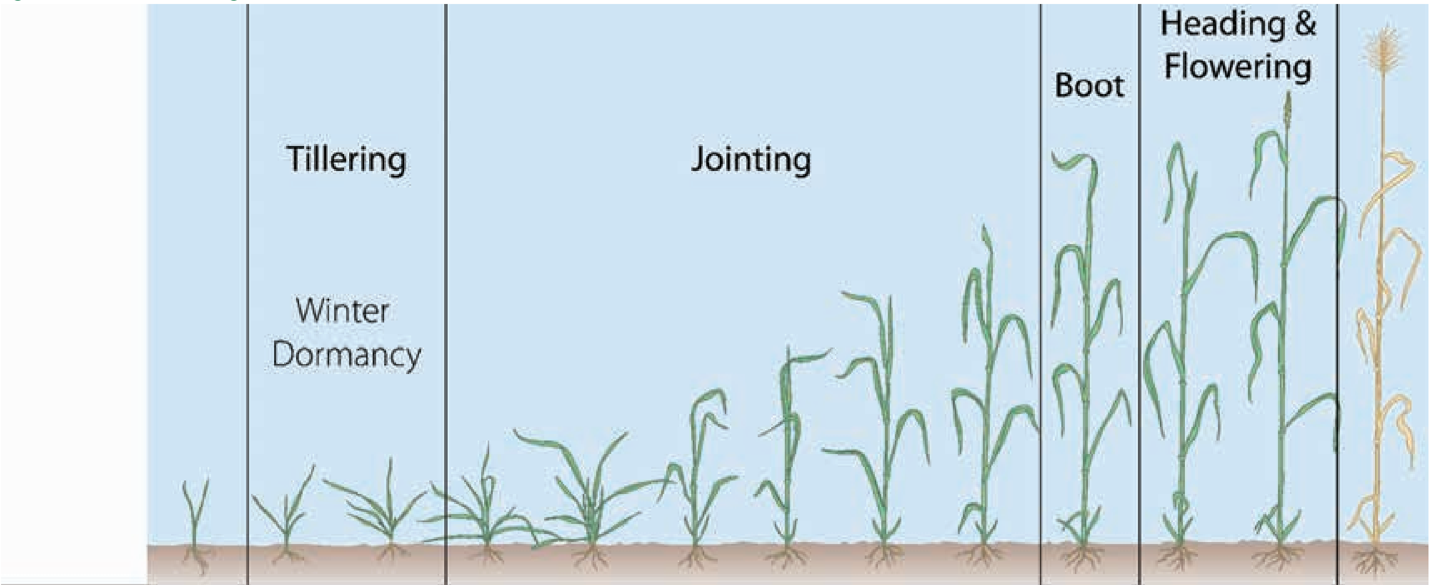


Feekes 11.4

Kernel ripe. Kernel moisture decreases from 30 to 15 per cent during ripening, and green plant tissue becomes straw.

Courtesy of: Romulo Lollato, Wheat and Forage Specialist, Department of Agronomy, Kansas State University - adapted for use in Saskatchewan.

Figure 1.3 Growth stages in cereals



Feekes	1	2	3	4	5	6	7	8	9	10	10.1	10.5	11
Zadoks	10	21	26	30	30	31	32	37	39	45	50	60	90

Adapted from the University of Illinois

Note: Winter dormancy only occurs in fall or winter cereals. Spring cereals will not have any winter dormancy and winter cereals seeded in the spring will not form heads.

Table 1.1 Zadoks scale

Growth Stage (GS)	Z	Description
GS0: Germination	00	Dry seed (caryopsis)
	01	Beginning of seed imbibition
	03	Seed imbibition complete
	05	Radicle emerged from caryopsis
	06	Radicle elongated, root hairs and/or side roots visible
	07	Coleoptile emerged from caryopsis
	09	Emergence: coleoptile penetrates soil surface (cracking stage)
GS1: Leaf Development[1,2]	10	First leaf through coleoptile
	11	First leaf unfolded
	12	2 leaves unfolded
	13	3 leaves unfolded
	19	9 or more leaves unfolded
GS2: Tillering[3]	20	No tillers
	21	Beginning of tillering: first tiller detectable
	22	2 tillers detectable
	23	3 tillers detectable
	29	End of tillering. Maximum no. of tillers detectable
GS3: Stem Elongation	30	Beginning of stem elongation: pseudostem and tillers erect, first internode begins to elongate, top of inflorescence at least 1 cm above tillering node.
	31	First node at least 1 cm above tillering node
	32	Node 2 at least 2 cm above node 1
	33	Node 3 at least 2 cm above node 2
	37	Flag leaf just visible, still rolled
	39	Flag leaf stage: flag leaf fully unrolled, ligule just visible

GS4: Booting	41	Early boot stage: flag leaf sheath extended
	43	Mid boot stage: flag leaf sheath just visible swollen
	45	Late boot stage: flag leaf sheath swollen
	47	Flag leaf sheath opening
	49	First awns visible (in awned forms only)
GS5: Inflorescence Emergence, Heading	51	Beginning of heading: tip of inflorescence emerged from sheath, first spikelet just visible
	52	20% of inflorenscence emerged
	53	30% of inflorenscence emerged
	54	40% of inflorenscence emerged
	55	Middle of heading: half of inflorescence emerged
	56	60% of inflorenscence emerged
	57	70% of inflorenscence emerged
	58	80% of inflorenscence emerged
	59	End of heading: inflorescence fully emerged
GS6: Flowering, Anthesis	61	Beginning of flowering: first of anthers mature
	65	Full flowering
	69	End of flowering: all spikelets have completed flowering but some dehydrated anthers may remain.
GS7: Development of Fruit	71	Watery ripe: first grains have reached half their final size
	73	Early milk
	75	Medium milk: grain content milky, grains reached final size, still green
	77	Late milk
GS8: Dough Development	83	Early dough
	85	Soft dough: grain content soft but dry. Fingernail impression held
	87	Hard dough: grain content solid. Fingernail impression held
	89	Fully ripe: grain hard, difficult to divide with thumbnail
GS9: Senescence	92	Over-ripe: grain very hard, cannot be dented by thumbnail
	93	Grains loosening in day-time
	97	Plant dead and collapsing
	99	Harvested product

[1] A leaf is unfolded when its ligule is visible or the tip of the next leaf is visible.
[2] Tillering or stem elongation many occur earlier than stage 13; in this case, continue with stage 21.
[3] If stem elongation begins before the end of tillering, continue with stage 30.

Corn Growth Stages

This identification system divides plant development into vegetative (V) and reproductive (R) stages. The (V) stages are designated numerically as V1, V2, V3, etc. through V(n) where (n) represents the number of leaves with visible collars. The first and last (V) stages are designated as VE (emergence) and VT (tasseling). The six reproductive stages are simply designated numerically.

Vegetative and Reproductive Stages

- Each leaf stage is defined according to the uppermost leaf whose leaf collar is visible.
- Loss of the lower leaves will begin at about V6 due to increased stalk size and nodal root growth. To determine the proper leaf stage after lower leaf loss, split the stalk lengthwise and inspect for internode elongation.
- The first node above the first elongated internode is generally the fifth leaf node. This fifth leaf node can be used as a reference point for counting the top leaf collar.

Figure 1.4 Corn growth stages

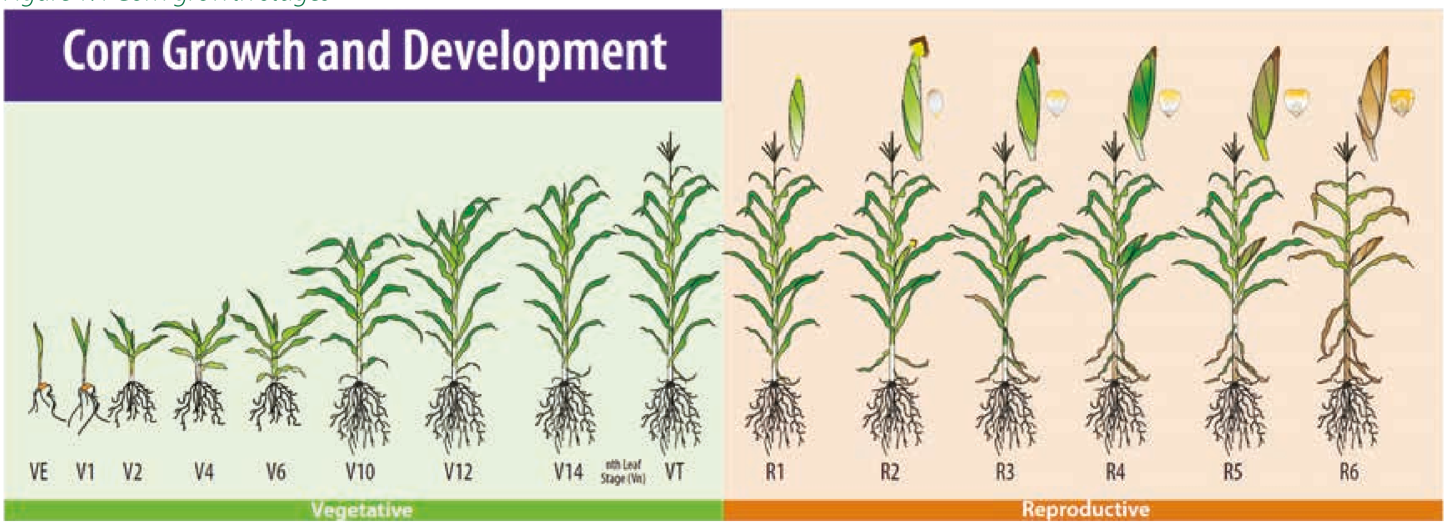


Figure 1.5 Corn milk line progression

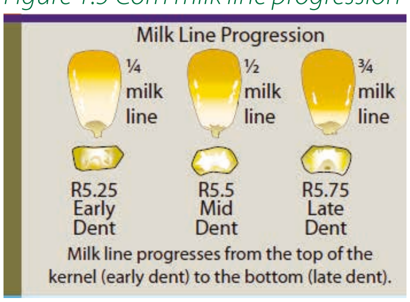
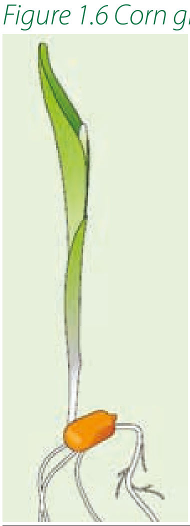


Figure 1.6 Corn growth stages



VE – Emergence

Emergence occurs when the first leaves, called the spike or the coleoptile, appear above the soil surface. The seed absorbs water (about 30 per cent of its weight) and oxygen for germination. The radicle root quickly emerges near the tip of the kernel, depending on soil moisture and temperature conditions. The coleoptile emerges from the embryo side of the kernel and is pushed to the soil surface by mesocotyl elongation. The mesocotyl encloses the plumule leaves that open as the structure approaches the soil surface.

V1 – First-Leaf

One leaf with collar visible (structure found at the base of the leaf). The first leaf in corn has a rounded tip. From this point until flowering (R1 stage), leaf stages are defined by the uppermost leaf with visible collars. The growing point is located below the surface until the late V5 stage.

Figure 1.6 Corn growth stages continued

V2 – Second-Leaf
Nodal roots begin to emerge below ground. Seminal roots begin to senesce. Frost is unlikely to damage corn seedling, unless it is extremely cold or the corn was shallowly planted.

V4 – Fourth-Leaf
Nodal roots are dominant, occupying more soil volume than seminal roots. Leaves still developing on apical meristem (primary growth of the plant).

V6 – Sixth-Leaf
Six leaves with collar visible. The first leaf with the rounded tip is senescent; consider this point when counting leaves. The growing point emerges above the soil surface. All plant parts are initiated. Sometime between V6 and V10, the potential number of rows (ear girth) is determined. Potential row number is affected by genetics and environment and is reduced by stress conditions. The plant increases in height due to stalk elongation; nodal roots are established in the lowest, below-ground nodes of the plant.

V10 – Tenth-Leaf
Brace roots begin to develop in the lower above-ground nodes of the plants. Until this stage, rate of leaf development is approximately two to three days per leaf.

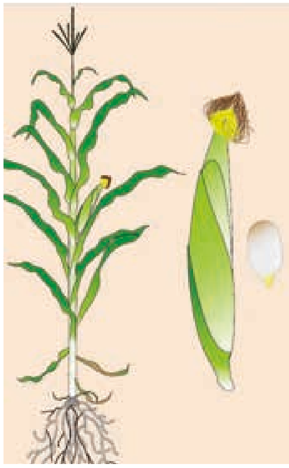
V14 – Fourteen-Leaf
Rapid growth. This stage occurs approximately two weeks before flowering. Highly sensitive to heat and drought stress. Four to six extra leaves will expand from this stage until VT.

VT – Tassel
Potential kernels per row is set, final potential grain number (number of ovules), and potential ear size are being determined. Last branch of the tassel is visible at the top of the plant. Silks may or may not have emerged. The plant is almost at its maximum height.

R1 – Silking
Flowering begins when a silk is visible outside the husks. The first silks to emerge from the husk leaves are those attached to potential kernels near the base of the ear. Silks remain active until pollinated. Pollen falls from the tassel to the silks, fertilizing the ovule to produce an embryo. Potential kernel number is determined. Maximum plant height is achieved. Following fertilization, cell division is occurring within the embryo.

Courtesy of: Ciampitti, I. A., Elmore, R. W., & Lauer, J. (2016). Corn Growth and Development. Manhattan, Kansas: Kansas State University - adapted for use in Saskatchewan.

Figure 1.6 Corn growth stages continued



R2 – Blister

Silks darken and begin to dry out. Kernels are white and blister-like in shape and contain a clear fluid. Kernels are approximately 85 per cent moisture; embryos develop in each kernel. Cell division is complete. Grain filling commences.

R3 – Milk

Silks dry out. Kernels are yellow, and a milk-like fluid can be squeezed out of the kernels when crushed between fingers. This fluid is the result of the starch accumulation process.

R4 – Dough

Starchy material within the kernels has dough-like consistency. Rapid accumulation of starch and nutrients occurs; kernels have 70 per cent moisture and begin to dent on the top. Material squeezed out of the kernel has dough-like consistency.

R5 – Dent

Most of the kernels are dented. Kernel moisture declines to approximately 55 per cent as the starch content increases.

R6 – Maturity

A black layer forms at the base of the kernel, blocking movement of dry matter and nutrients from the plant to the kernel. Kernels achieve maximum dry weight (30 to 35 per cent moisture) and are physiologically mature.

Courtesy of: Ciampitti, I. A., Elmore, R. W., & Lauer, J. (2016). Corn Growth and Development. Manhattan, Kansas: Kansas State University - adapted for use in Saskatchewan.

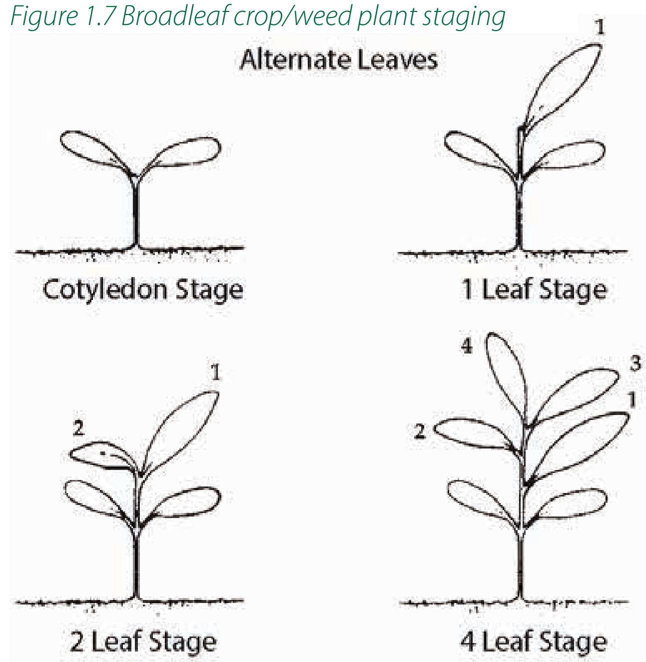
Broadleaf Crops and Weeds Plant Staging

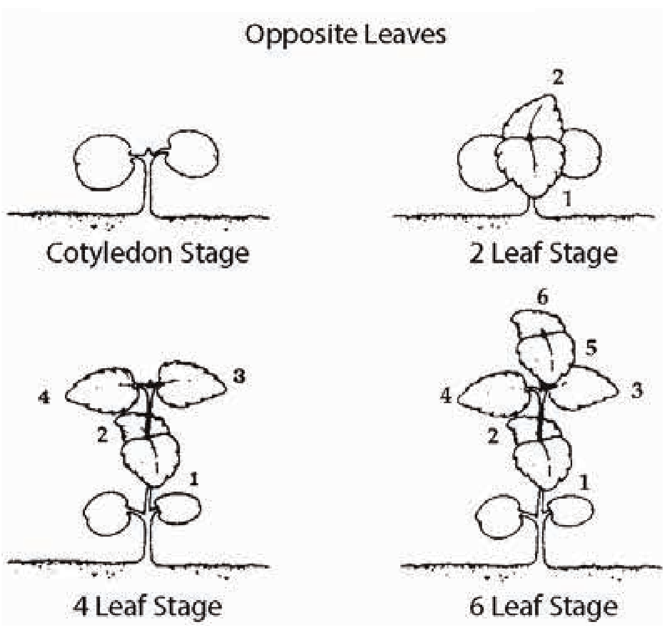
Cotyledons are the leaves that first emerge from the soil on a broadleaf plant, but are not considered the first true leaves for plant staging purposes. The first true leaves appear from the growing point directly after the cotyledons.

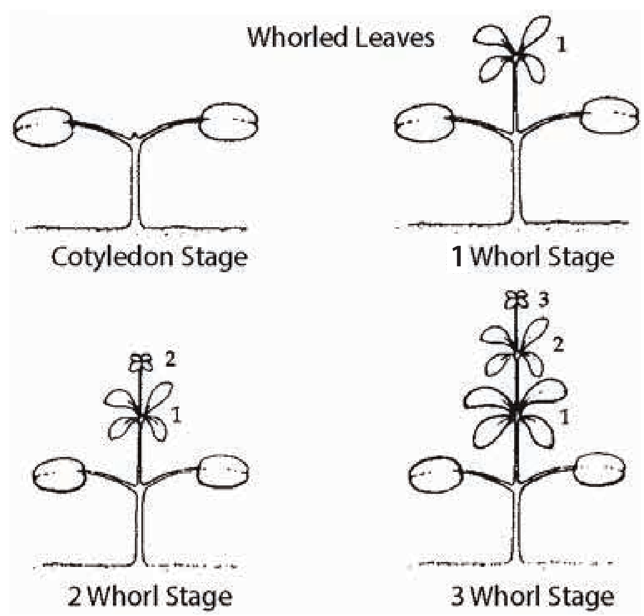
Counting Leaves

- Determine the crop/weed leaf orientations:
- Alternate leaves-one single leaf is attached individually in an alternating pattern (count leaves individually).
- Whorled leaves-more than two leaves are attached at the same point around the stem (count each whorl as a leaf).
- Some plants develop a basal rosette before developing a specific leaf orientation. Examples: canola, dandelions, shepherd's purse and night flowering catchfly.
- Do not count cotyledons as a leaf.
- Count leaves when visibly separated from the terminal bud.

Figure 1.7 Broadleaf crop/weed plant staging



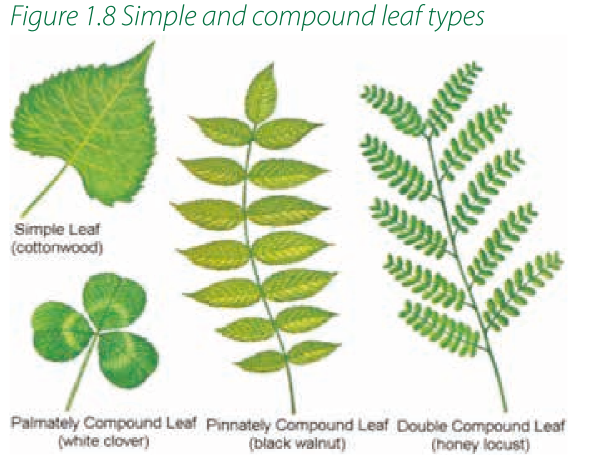




Leaf types

- **Simple leaf:** single leaf blade with veins that pan off a single midrib that are attached at the petiole.
- **Compound Leaf:** two or more leaflets attached to the midrib separately through the rachis.
- **Pinnate:** leaflets are arranged either alternating or opposite that branch directly off a rachis.
- **Palmate:** leaflets are attached from a common point at the petiole and branch off like fingers from a palm.

Figure 1.8 Simple and compound leaf types



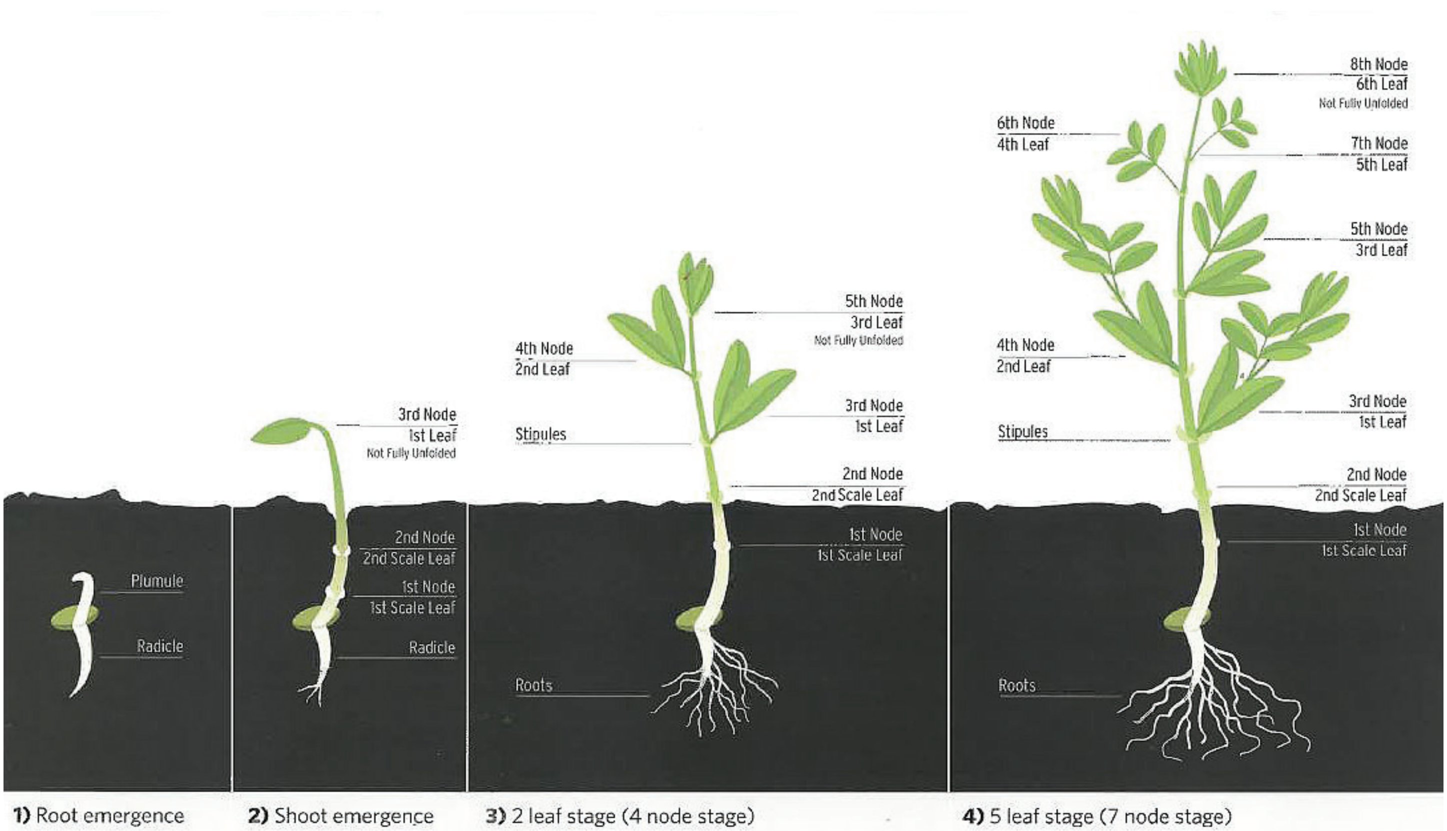
Courtesy of: @2022 Coredifferences

Pulse Plant Staging

Lentil Plant Stages and Development

- Lentil seedlings can produce a new node every four to five days under good growing conditions.
- For staging purposes, only fully open leaves should be counted.
- Just prior to flowering, new leaves will develop a short tendril at the leaf tip.
- Vigorously growing lentil plants with adequate space will produce two or more primary shoots from the base of the stem.
- The first few flowers on the main stem may abort.
- Flower stalks produce one to three flowers that will develop into pods after self-pollination.
- Pods usually contain one to two seeds.
- The main contribution to yield is from flowers on secondary branches. These branches arise from the nodes immediately below the first flowering node of the main stem. Up to five of these branches may develop.
- When growing conditions are suitable for extremely high yield, the secondary branches also produce additional seed-bearing branches.
- Since lentil plants have an indeterminate growth habit, they continue to flower until they encounter some form of stress, such as drought, heat, frost, nitrogen deficiency, mechanical damage or chemical dessication.
- Pulse crops or legumes do not have cotyledons above ground and are staged by the number of nodes or number of leaves.
  - The first nodes are often below ground.
  - The first and second nodes have reduced leaves called scale leaves and are not considered true leaves.
  - The first true leaf is located at the third node position. Therefore, node and leaf stages always differ by two.

Figure 1.9 Lentil growth stages



Courtesy of: Saskatchewan Pulse Growers

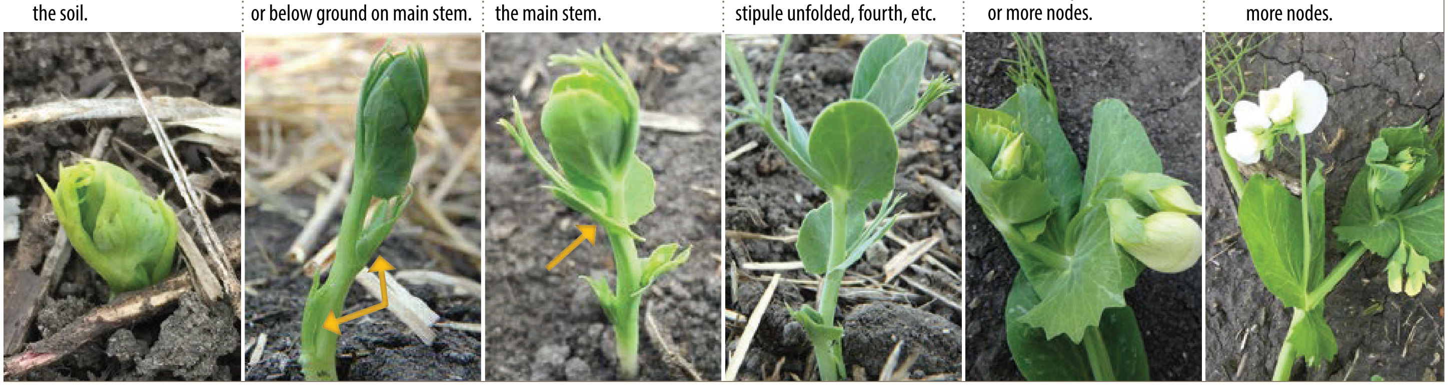
Note: When staging for herbicide application, check the specific herbicide label for counting method on nodes. Most often the first above ground leaf node (not the first scale node) is considered to be the first node to begin staging from.

Field Pea Plant Stages and Development

- Scales leaves are the first to develop at the VS stage but are not considered true leaves and are normally not considered when counting nodes. This distinction is crucial for accurately counting nodes before pesticide applications. Always refer to the label to confirm how the manufacturer defines staging for application timing.
- The first true leaf at the third node position usually has a pair of leaflets and a tendril. In semi-leafless peas, tendrils replace the leaflets.
- Under good growing conditions, two nodes can develop in seven days and basal branches will develop from one or both of the nodes with scale leaves by the six-leaf stage.
- During vegetative development, the clam leaf is the uppermost two leaves on the stem that are upright and close together, resembling a clam. For staging purposes, leaves must be fully opened to count, so clam leaves are excluded if present.
- Flowers begin to be produced at about the twelfth to sixteenth node stage.
- Usually one-to-three self-pollinated flowers are produced at each flowering node.
- Pods are fully elongated within seven to 10 days. Over 24 to 30 days the pods mature until the dry seed stage is reached.
- Varieties are relatively indeterminate and a stress is needed to bring on maturity.

Figure 1.10a Field pea growth staging guide

VE *Emergence*	**VS** *Scale leaves*	**V1** *First node*	**V2 to Vn**	**R1** *Flower bud*	**R2** *Beginning bloom*
Epicotyl pushed through the soil.	Two scale leaves present above or below ground on main stem.	First unfolded stipule, clasping the main stem.	Second stipule unfolded, third stipule unfolded, fourth, etc.	Flower bud present at one or more nodes.	Flower open at one or more nodes.



Stipules are modified leaves at the base of each above-ground node along the main stem. Tendrils replace true leaves on semi-leafless varieties.

R3 *Flat pod*	**R4** *Full pod*	**R5** *Beginning maturity*	**R6** *Mid maturity*	**R7** *Full maturity*	*Ready to harvest*
Flat pod at one or more nodes.	Green seeds fill the pod cavity at one or more nodes.	Leaves and lower pods start to turn yellow.	Yellow seeds fill the pod cavity at one or more nodes.	Most pods (75–80%) are golden brown, seed moisture is 25–30%.	All pods are golden brown, seed moisture is <20%.

Courtesy of: Manitoba Pulse and Soybean Growers

Figure 1.10b Field pea maturity guide

R4 *Full pod*	**R5** *Beginning maturity*	**R6** *Mid maturity*	**R7** *Full maturity*	*Ready to harvest*
Green seeds fill the pod cavity at one or more nodes.	Leaves and lower pods start to turn yellow.	Yellow seeds fill the pod cavity at one or more nodes.	Most pods (75–80%) are golden brown, seed moisture is 25–30%.	All pods are golden brown, seed moisture is <20%.

FIELD VIEW

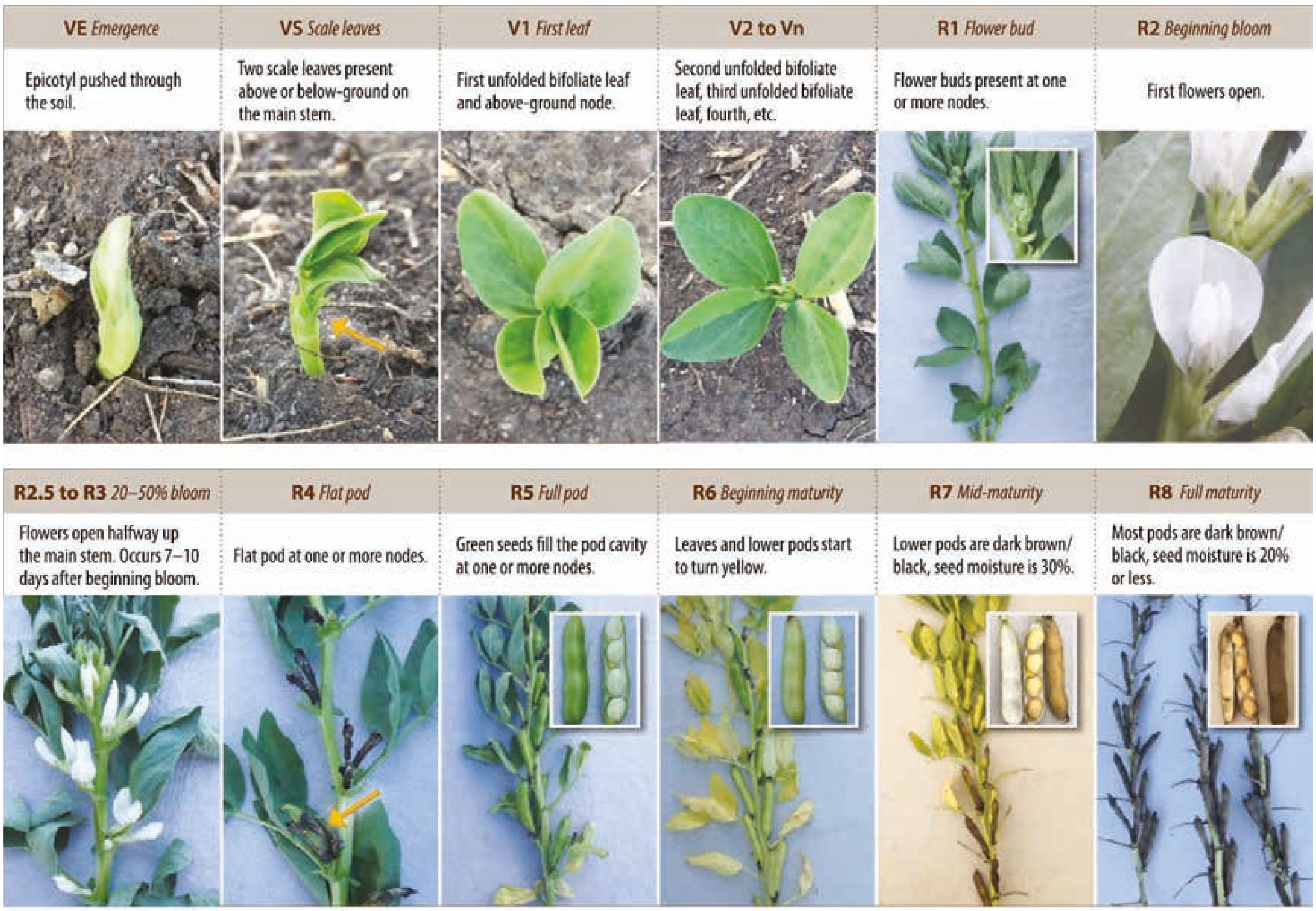
R4 *Full pod*	**R5** *Beginning maturity*	**R6** *Mid maturity*	**R7** *Full maturity*	*Ready to harvest*

Courtesy of: Manitoba Pulse and Soybean Growers

Faba Bean Plant Stages and Development

- Faba beans germinate with the cotyledon remaining below ground.
- The first two nodes develop below or at soil surface and the small leaves associated at the nodes are called scale leaves.
- Regrowth is possible from buds at the base of these scale leaves.
- The first true leaf will be produced at the third node position.
- The first two leaves consist of two leaflets each and remaining leaves consist of three or more leaflets.
- During vegetative stages, faba bean plants can produce new nodes every five days.
- When determining crop stage, include nodes where the leaves or pairs of leaves are fully open or unfolded. Youngest or newly emerging leaves are not included in staging unless completely open.
- There are both determinant and indeterminant faba bean varieties.

Figure 1.11 Faba bean growth stages

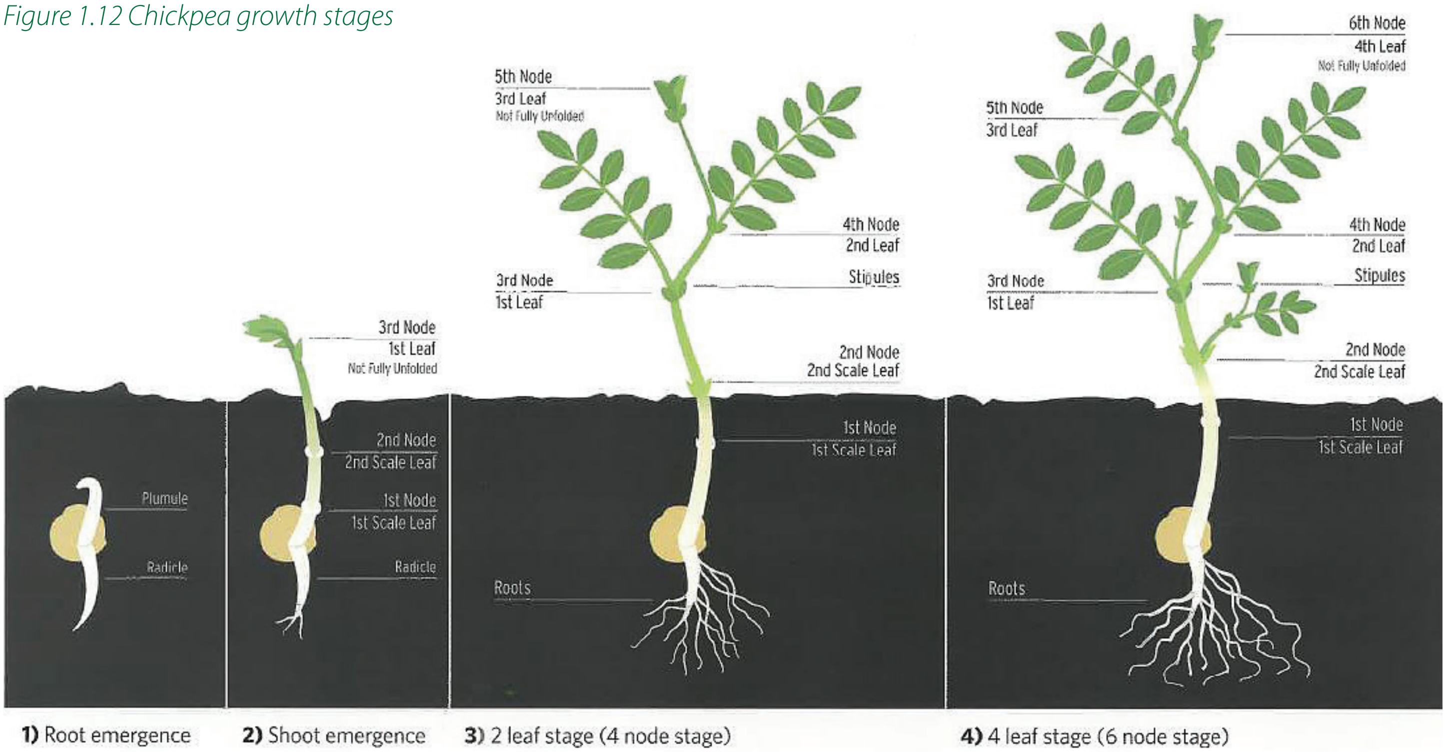


Courtesy of: Manitoba Pulse and Soybean Growers

Chickpea Plant Stages and Development

- Chickpeas germinate with the cotyledon remaining below ground.
- The first two nodes of chickpeas develop below or at the soil surface and the small leaves associated at these nodes are called scale leaves.
- Regrowth is possible from buds at the base of these scale leaves.
- The first true leaf is produced at the third node position.
- Growth is rapid during vegetative stages and chickpea seedlings can produce new nodes every three to four days.
- Chickpea plants will produce up to seven primary branches originating near ground level, usually leading to an erect growth habit.
- Chickpeas have an indeterminate growth habit and will continue to flower while growing conditions remain favourable for vegetative growth.

Figure 1.12 Chickpea growth stages



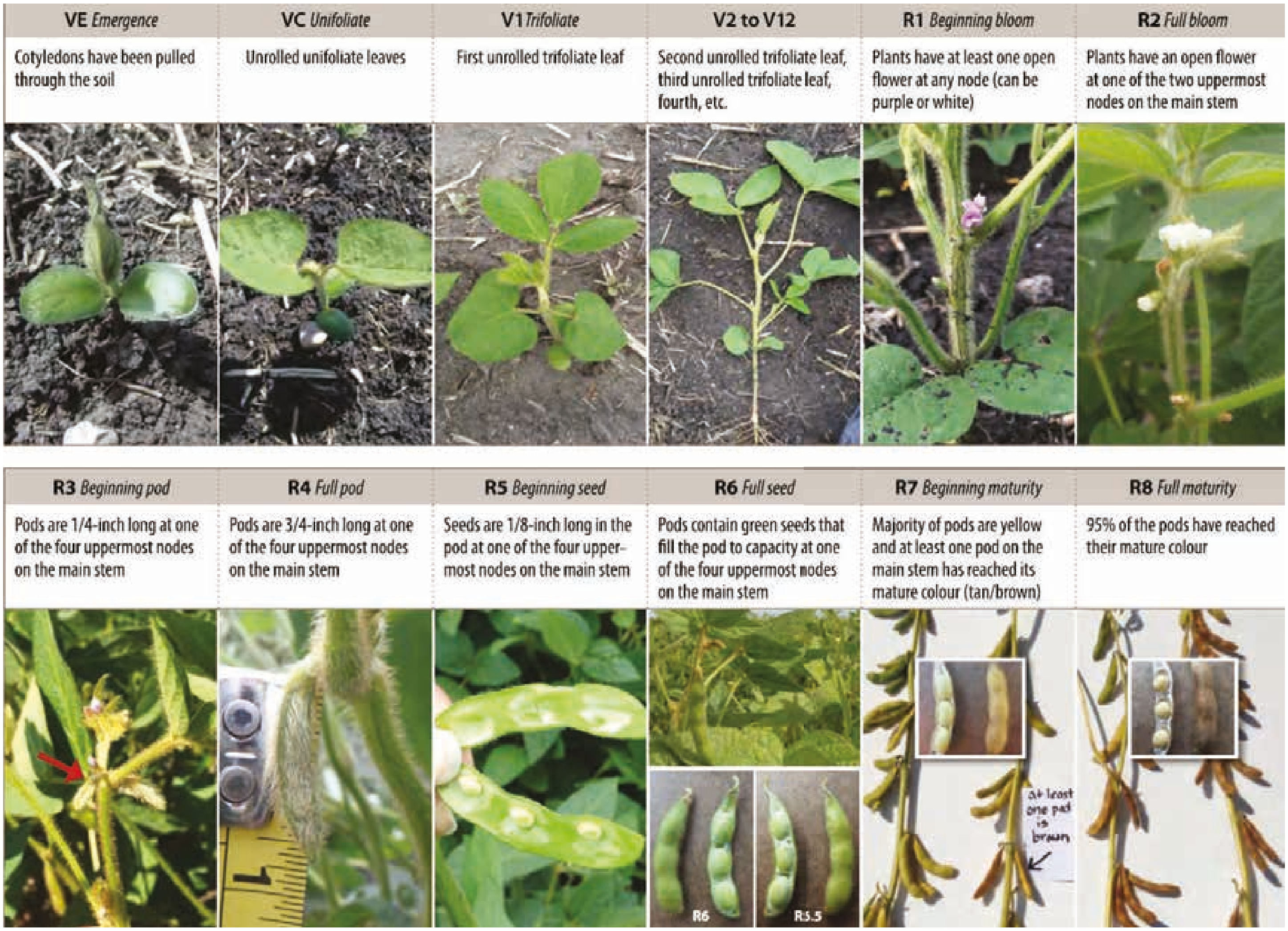
Courtesy of: Saskatchewan Pulse Growers

Note: When staging for herbicide application, check the specific herbicide label for counting method on nodes. Most often the first above ground leaf node (not the first scale node) is considered to be the first node to begin staging from.

Soybean Plant Growth Stages and Development

- Soybean germination takes roughly seven to 10 days depending on soil temperature (optimum soil temp. 15 to 20 C) and moisture conditions. Emergence (VE) occurs after germination and cotyledons push through the soil surface (epigeal emergence)..
- There are both determinant and indeterminant soybean varieties.
- Soybeans should be seeded 3/4 to 1 1/2 " deep.
- The first true leaves emerge at the first node, where they are simple unifoliate leafs (VC) and are opposite of one another.
- The V1 stage is when the first trifoliate emerges and when nitrogen fixing nodules begin to form on the root system (Bradyrhizobium japonicium).
- Once the soybean has reached V2 vegetative growth stage nitrogen fixation begins to occur.
- The R1 stage, the beginning of the reproduction growth stage, occurs when the buds begin to bloom. After this, flowering continues for three to five weeks. By the R3 stage, we can observe the initial development of pods. Once the soybean plant reaches 95 per cent brown colouration, it is classified as R8 and considered fully mature.

Figure 1.13 Soybean growth stages



Courtesy of: Manitoba Pulse and Soybean Growers Association

Dry Bean Plant Stages and Development

- Dry beans can have an indeterminate or determinate growth habit.
- Determinate (bush) plants have a central stem with five to nine nodes. From the basal nodes, two or more branches grow.
- Indeterminate bush-type or prostrate vine plants will have a mainstem with 10 to 12 nodes.
- Soil temperatures should be a minimum of 12 C for germination.
- When staging dry beans, the V stage is the vegetative growth stage, and the R stage is the reproductive stage when the flowers begin to emerge.
- Dry beans require a warm season and adequate soil moisture.
- Days to flower are typically 50 days from emergence.
- They reach maturity between 105 to 115 days from planting.

Figure 1.14 Drybean growth stages

VE *Emergence*	**VC** *Unifoliate*	**V1** *Trifoliate*	**V2 to Vn**	**V5** *bush/determinate* ***or*** **V8** *vine/indeterminate*
Hypocotyl emergence.	Unrolled cotyledons and unifoliate leaves.	First unrolled trifoliate leaf.	Second unrolled trifoliate leaf, third unrolled trifoliate leaf, fourth, etc.	Flower buds visible.

R1 *Beginning bloom*	**R2** *Beginning pod*	**R3** *50% bloom*	**R4** *Full Pod*	**R5** *Beginning seed*
One open flower at any node.	Pods 1/2 inch long at the first flower position (base of the plant) or *pin bean* stage.	Pods 1 inch long at the first flower position. Determinate plants becoming denser, but not taller.	Pods 2 to 3 inches long at the first flower position.	Pods 3 to 4 inches long. Seeds discernible.

R6 *50% seed*	**R7** *Full seed*	**R8** *Beginning maturity*	**R8.5** *Mid maturity*	**R9** *Full maturity*	*Ready to harvest*
Seeds at least 1/4 inch in length over long axis.	Oldest pods with fully developed seeds.	Leaves yellowing over half the plant. Small pods ripening.	Oldest pods beginning to ripen.	At least 80% of pods ripening, 30% of leaves still green.	All pods ripe, 15–18% seed moisture.

FIELD VIEW

R7 *Full seed*	**R8** *Beginning maturity*	**R9** *Full maturity*	*Ready to harvest*

Courtesy of: Manitoba Pulse and Soybean Growers Association

Flax Growth and Development

- The life cycle of flax consists of a 45 to 60 day vegetative period, 15 to 20 day flowering period and 30 to 40 day maturation period.
- Flax can be seeded up to the first day of June without yield penalty. Due to the plant's hardiness, it could be seeded early as it can withstand temperatures as low as -3 C for short periods of time at the cotyledon stage.
- Flax has one main stem, but two or more branches may develop from the base of the plant when plant density is low and soil nitrogen is high.
- Flax prefers to be grown in cool temperate climates at 18 to 21 C.
- The main stem and branches give rise to a multi-branched, irregular arrangement of flowers. New flowers will open in the morning and will only bloom for one day, typically shedding the petals by mid-day. Flowering can last anywhere from 15-25 days depending on growing conditions.
- Pollination is not required by insects as flax is efficient at self-pollination.
- Ripening of the boll begins 20 to 25 days after flowering. The boll has five segments which are divided by a wall with each segment producing two seeds. With complete seed set, the boll contains 10 seeds, though an average of six to eight seeds per boll is usual.

Figure 1.15 Flax growth stages

Figure 1.15 Flax growth stages continued

First flower Capsules start forming Continuation of branching	Late flower Most branches and capsules formed	Green capsule Seed white lower leaves yellow	Brown capsule Seeds light brown (or otherwise pigmented) plump and pliable-maximum dry matter branches, stems and upper leaves green/yellow middle leaves partly senescent and lower leaves shriveled and dropped.	Seed ripe Seeds brown (or otherwise pigmented) and rattle in capsules branches and upper leaves senescent but stem still green/yellow

Courtesy of: Sask Oilseeds

Canola and Mustard Development and Stages

Canola and mustard follow a very similar life cycle and growth pattern and can be staged in a similar manner. The BBCH scale is a uniform decimal system to describe the growth stage scale of many different crops and weeds. It will be used in this handbook for the purpose of describing the growth stages of canola and mustard.

There are two species of canola, *Brassica rapa* (Polish canola) and *Brassica napus* (Argentine canola). *B. rapa* is the historic species of rapeseed. *B. napus* is self-pollinating and *B. rapa* is not. *B. napus* is the canola most widely grown in Canada today. This manual will be referring to B. napus when describing canola for the rest of the book.

Throughout the life cycle, canola and mustard plants have eight principle growth stages: germination, leaf development, stem elongation, inflorescence emergence, flowering, fruit development, ripening and senescence. The staging system is organized by these principle growth stages and expanded to reflect the progression through each stage. Staging of crops is important for optimal timing of harvest and pest management strategies.

Germination

- New stem or hypocotyl extends and pushes the cotyledons to the soil surface.
- Cotyledons turn green on exposure to sunlight.
- Emergence takes four to 15 days, depending on environmental conditions.

Leaf Development

- The growing point is above the surface between the two cotyledons.
- Plant is at risk of injury from insects and frost due to exposed growing points.
- Root development occurs at a rate of about two centimetres per day.
- First true leaf develops within four to eight days of emergence.
- There is no definite number of leaves that will develop. Leaf numbers could range from nine to 30.

Stem Elongation

- Stem elongation overlaps with leaf development and flower development.
- At or just prior to stem elongation, flowering and branch initiation begins.
- The main stem reaches 30 to 60 per cent of its maximum length just prior to flowering.

Flower Development

- Flower buds remain closed during early stem elongation and can be seen by peeling back young leaves.
- Green bud stage occurs when the flower buds can be seen from above but are still not free from the leaves.
- The yellow bud stage is when the lower flower buds become yellow.
- Development of branches is not fixed until the end of flowering.

Flowering and Podding

- Flowering begins with the opening of the lowest bud on the main stem and continues upward with three to five or more flowers opening per day.
- All of the buds that will develop into open flowers on the main stem will likely be visible within three to 10 days.
- Under reasonable growing conditions, flowering of the main stem will continue from 14 to 21 days for both species.
- Full plant height is reached at full flowering (50 per cent of flowers on main raceme open, older petals falling) due to the overlap of growth stages.
- The first buds to open become the pods lowest on the main stem or secondary branches.
- By mid-flower lower pods have started elongating.

Seed Development and Ripening

- Normally a pod contains 15 to 40 seeds.
- About 35 to 45 days after the first flower opens seed filling is complete.
- Immature seeds, when filled, contain about 40 to 45 per cent moisture. The seed coat then begins to turn from green to yellow or brown, depending on the variety.
- Seed moisture is rapidly lost at a rate of two to three per cent or more per day, depending on growing conditions.
- At 40 to 60 days after first flower, the seeds in the lower pods will have ripened and fully changed colour. As the seed coat changes colour so does the seed. Staging is based on seed colour change
- When completely mature the seed is uniformly bright yellow or brown to black in colour.
- Optimum stage to swath for both yield and quality is up to 60 per cent seed colour change.
- *B. rapa* varieties may be swathed earlier at 40 per cent seed colour change on the main stem due to their tendency to clear chlorophyl more readily.

Table 1.2 Harper-Berkenkamp[1] Canola/Rapeseed Plant maturity scale

Stage	Description	Approximate BBCH[2] equivalent
0	**Pre-emergence**	00 - 08
1	**Seedling**	09 - 11
2	**Rosette**	
2.1	First true leaf expanded	
2.2	Second true leaf expanded	12
	(add 0.1 for each additional leaf)	13 - 39
3	**Bud**	
3.1	Inflorescence visible at centre of rosette	51
3.2	Inflorescence raise above level of rosette	53
3.3	Lower buds yellowing	59
4	**Flower**	
4.1	First flower open	60
4.2	Many flowers opened, lower pods elongating	65
4.3	Lower pods starting to fill	69
4.4	Flowering compete, seeds enlarge in lower pods	71
5	**Ripening**	
5.1	Seeds in lower pods full size, translucent	75-79
5.2	Seeds in lower pods green	80
5.3	Seeds in lower pods green-brown mottled; 10% of all pods ripe	81
5.4	Seeds in lower pods brown; 30% of all pods ripe	83
5.5	Seeds in all pods brown; plant senescent; nearly 100% of all pods ripe	89

1. Harper, F. R. and Berkenkamp, B. Revised growth-stage key for Brassica campestris and B. napus. Canadian Journal of Plant Science 55, 657-658. 75.

2. Lancashire, P.D. et al. A uniform decimal code for growth stages of crops and weeds. Annals of applied biology 119, 561-601 (1991).

Table 1.3 How to distinguish mustard from canola

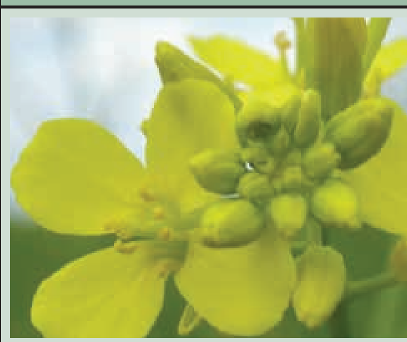
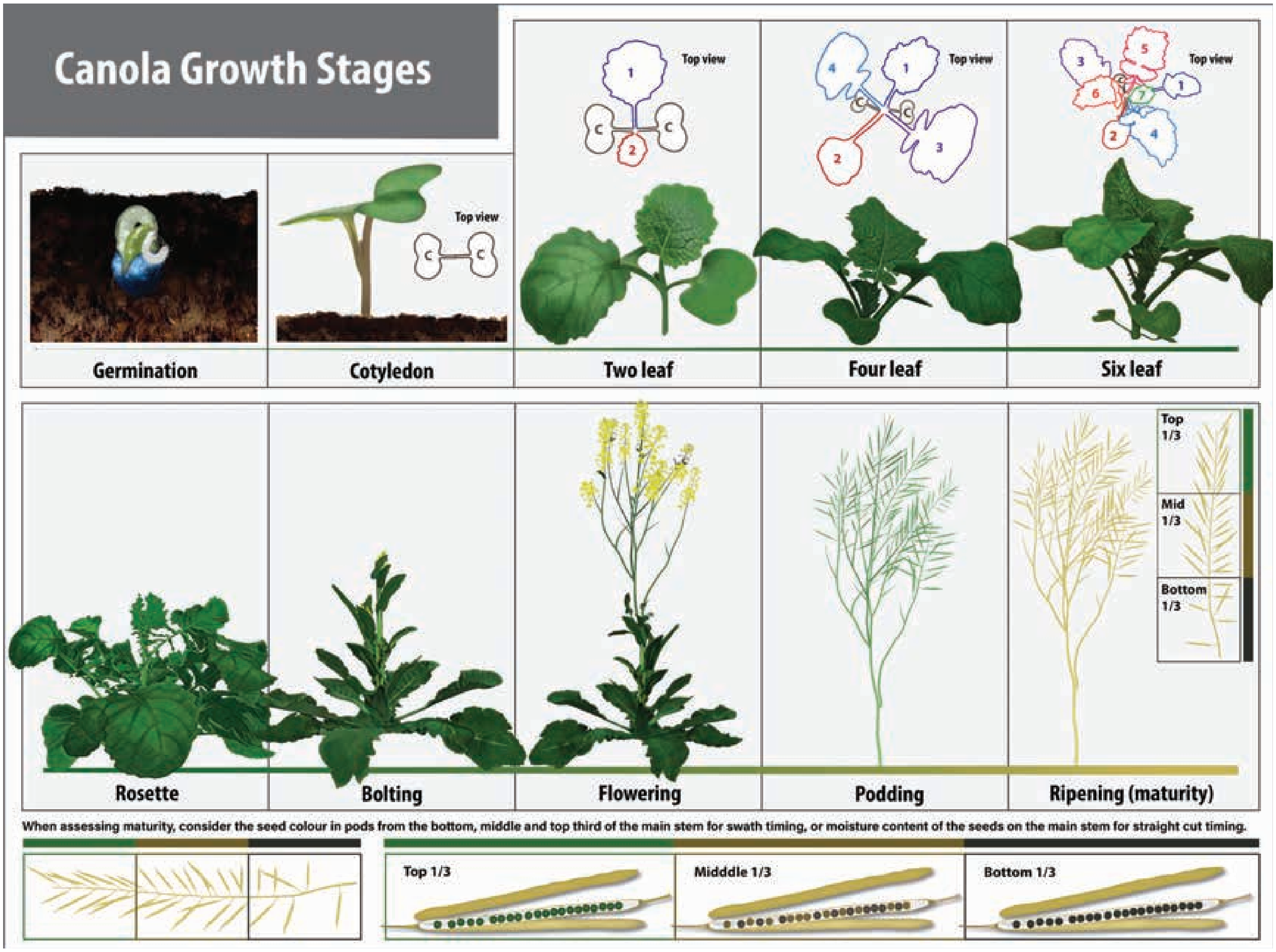
	Canola *(Brassica napus)*	**Brown or oriental mustard** *(Brassica juncea)*	**Yellow mustard** *(Sinapis alba)*
Seedling	 Heart-shaped cotyledons and hairless leaf stalks. First true leaves have a hairless upper surface with scarce hairs on the underside of the leaf.	 Heart-shaped cotyledons and hairless leaf stalks. First true leaves are covered with hairs on both the upper and lower leaf surfaces. Hairs on leaves are less dense than on yellow mustard leaves.	 Heart-shaped cotyledons have a few hairs on the edges and upper surface. Stems and leaf stalks are densely pubescent (hairy). First true leaves have a dense covering of hair on both the upper and lower surfaces.
Adult Leaves	 Adult leaves are dark bluish-green, waxy and either hairless or with a few sparse hairs near the leaf margin. The leaves are rounded and partially clasp the stem.	 Leaves are pale green with hairs on the first leaves and leaf margins. The lower leaves will be deeply lobed, while the upper leaves will be narrower and not lobed. The leaf will terminate higher up on the petiole and will not clasp the stem.	 Leaves are light-green, densely pubescent and deeply lobed. The leaf will terminate higher up on the leaf stalk and will not clasp the stem.
Flowers	 Yellow flowers	 Pale yellow flowers	 Yellow flowers that are smaller than canola flowers

Table 1.3 How to distinguish mustard from canola continued

	Canola *(Brassica napus)*	**Brown or oriental mustard** *(Brassica juncea)*	**Yellow mustard** *(Sinapis alba)*
Stems	Hairless and smooth	Hairless and smooth	Pubescent with a lot of small hairs on the stems and petiloes.
Pods	 Long narrow pods with a smooth, medium conical peak. Pods are usually positioned at a right angle to the stem.	 Smooth long, conical beaked pods. The pods are usually positioned 45° to the stem.	 Pods are long, flat and covered with small hairs. Pods are positioned at a right angle to the stem.
Seeds	 Seeds are black in colour and spherical to oval in shape. They are larger than brown and oriental mustard but smaller than yellow mustard seeds.	 **Brown Mustard** Seeds are reddish brown to dark brown in colour and are 2 mm or less in diameter. Seeds are spherical or oval in shape.	 Seeds are light creamy yellow to yellow with the occasional seed being light or yellowish brown. Seeds are spherical or oval in shape with a diameter of 2 to 3 mm.
		 **Oriental Mustard** Seeds are predominately yellow to dark yellow in colour with some seeds light brown to dark brown. Oval in shape with a width of 1.2 to 2 mm and a length of 1.6 to 3 mm.	*Courtesy of: SaskMustard*

Figure 1.16 Canola staging guide



Courtesy of: Canola Council of Canada

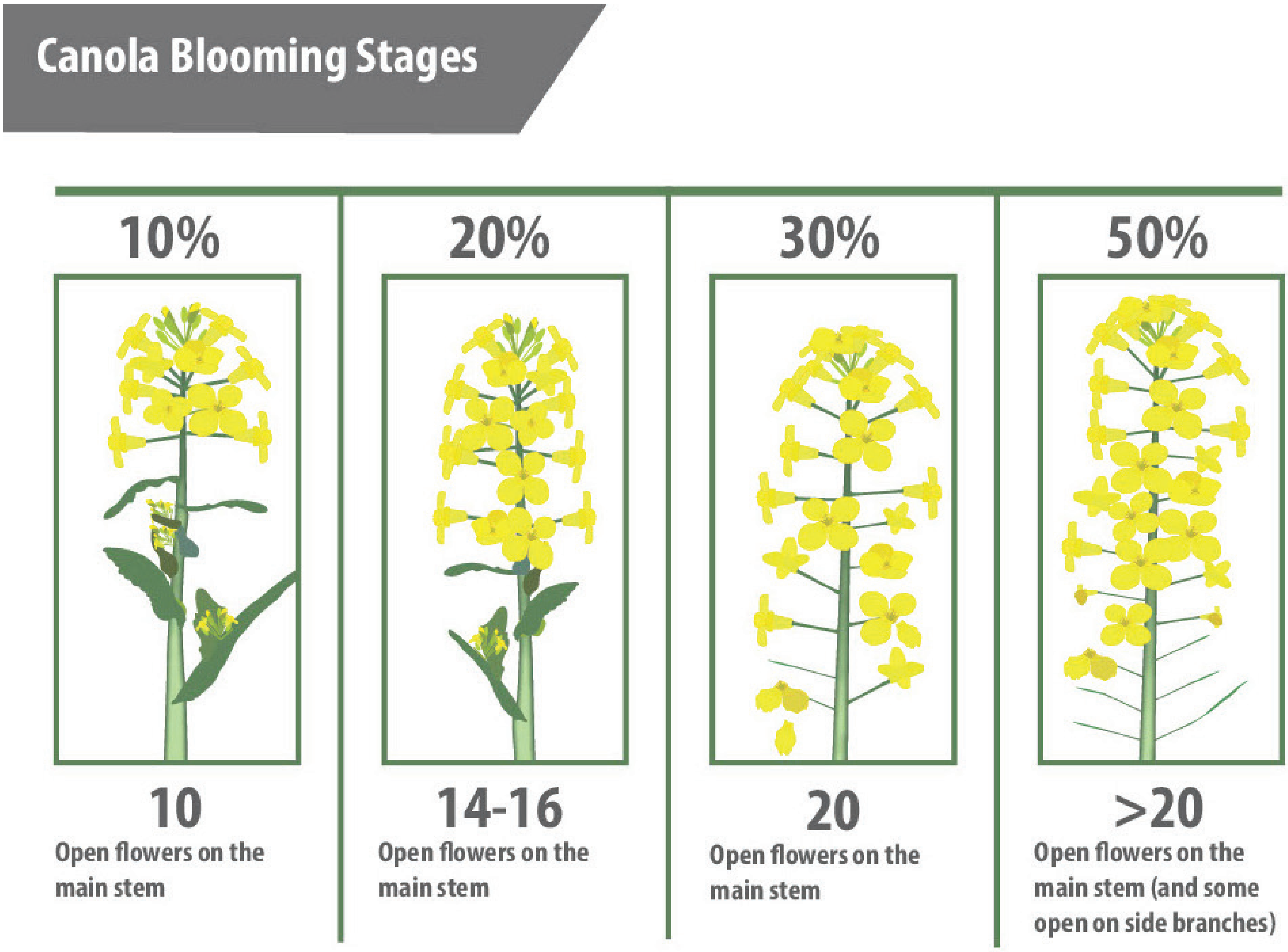
Assessment of Flower Bloom in Canola

Although different fungicides may have slightly different recommendations for spray timing, they are most effective when made at or before 50 per cent flowering. For this reason, assessing flower stages correctly is critical.

Flowering

- Flowering begins with the opening of the lowest bud on the main stem and continues upward with three to five or more flowers opening per day.
- Flowering at the base of the first secondary branch begins two to three days after the first flower opens on the main stem.
- Under reasonable growing conditions, flowering of the main stem will continue for 14 to 21 days.
- In general, the crop takes two to four days to move from first flower to 10 per cent flower:
    - One to two days from 10 per cent to 20 per cent flower,
    - One to two days from 20 per cent to 30 per cent flower, etc.
- Colour intensity steadily increases until its maximum intensity at 50 per cent flower. By 60 per cent flower, colour intensity begins to decrease.

Figure 1.17 Percentage of canola bloom



Courtesy of: Canola Council of Canada

Calculating Seeding Rates

Thousand kernel weight (TKW), germination rate and target plant populations are needed when calculating seeding rates. Crops and varieties can vary significantly in seed size, especially pulses and not knowing your TKW could mean seeding too heavily and spending more on seed than needed or seeding too lightly and limiting yield potential. Emergence rate is more difficult to estimate, as it is dependent on germination and environmental conditions.

Expected seedling survival is typically five to 20 per cent less than the germination rate with pulses and cereals — more under ideal conditions and less under adverse conditions. For canola, expected survival rates range from 40 to 60 per cent. Factors to take into account when determining the expected seedling survival are seeding date, soil temperature, moisture and texture, as well as seed quality and possible soil-borne diseases and insect pressures. The amount of seed-placed fertilizer and the seeding depth are factors that can also affect seedling survival. The formula below should be used to determine the target seeding rate:

Formula:

$$\text{Seeding Rate in kilograms per hectare (kg/ha)} = \frac{\text{(target population per square metre x TKW* in grams)}}{\text{\% field emergence or survival (in whole number, i.e. 85)}}$$

To convert to lbs/acre multiply seeding rate (kg/ha) x 0.89 *TKW = Thousand kernel weight

For example: with CDC Amarillo yellow peas, the target plant population is 85 plants/m^2. A seed lot with TKW of 235 grams and germination at 98 per cent under good emergence conditions (using 88 per cent emergence, which is 10 per cent less than the germination rate) would have a target seeding rate of: 85 x 235 / 88 = 227 kg/ha, or 202 lbs/ac or 3.4 bu/ac.

Courtesy: SaskSeed Guide

Table 1.4 Target plant population and thousand kernel weight (TKW) in grams for various crops

Crop	Target Plant Population (per square metre)	Thousand Kernel Weight (TKW) in grams
Barley-2 row	210-250	40-50
Barley-6 row	210-250	30-45
Camelina	210	1–1.3
Canary Seed	500-570	7-8.5
Canola-*Brassica rapa*	60-100	2-3
Canola-*Brassica napus*	60-100	2.5-7.5
Chickpea	44	220-450
Corn (grain)	7	200-270
Dry Bean	40	160-900
Durum	210-250	41-45
Faba Bean	45	350-425
Fall Rye	250	30-35
Flax	300-400	5-6.5
Hemp-Grain	100-125	12-18
Lentils (Green, large)	130-190	64-75
Lentils (Red)	130	35-40
Mustard-Brown/Oriental	70-120	2–3
Mustard-Yellow	70-120	5.5-6.5
Oat	350	30-45
Pea	85	125-300
Soybean	44-57	n/a
Triticale-spring	310	42-48

Table 1.4 Target plant population and thousand kernel weight (TKW) in grams for various crops continued

Triticale-winter	250	43-46
Wheat-CPS	250	39-50
Wheat-Hard Red Spring	250	31-38
Wheat-SWS	210-250	34-36
Wheat-winter	250	30-36

Thousand kernel weights (TKW) can be determined by counting out 1,000 seeds and weighing the seed. Seed germination can be obtained through a seed test or measured at home.

Recommended Minimum Soil Temperature and Seeding Depth

Soil temperature at the depth of seeding can be used as a guide to determine when to start seeding. Minimum soil temperature recommendations are an average of morning and afternoon readings taken from representative spots in the field. Cold soil temperatures at the time of seeding can impact rate of emergence and in some cases even plant population numbers and uniformity of plant stand. The recommended minimum temperatures are those required for germination to occur. Emerged plants may be subject to frost injury depending on the crop type and where growing points are located in relation to the soil surface.

Table 1.5 Recommended Minimum Soil Temperatures and Seeding Depths

Crops	Recommended Minimum Average Soil Temperature at Seeding Depth (Celsius)	Recommended Seeding Depth (cm/inches)
Barley	3-5	3.8-4.5/(1.5-1.75)
Canaryseed	5	<6 cm/(<2.5)
Canola (*B. napus*)	5	1.5-2.5/(0.5-1.0)
Chickpeas-Desi	7	3.5-6/(1.5-2.5)
Chickpeas-Kabuli	10	3.5-6/(1.5-2.5)
Corn	10	3.81 - 5.08/1.5 - 2.0
Dry Beans	12	5-6/(2-2.5)
Faba Beans	3-5	5.1-7.6/(2-3)
Flax	5	2.5-4.0/(1.0-1.5)
Lentils	5	2.5-7.5/(1-3)
Mustard	5	1.5-2.5/(.5-1.0)
Oats	5	2.5-5.0/(1.0-2.0)
Peas	5	3-8/(1.2-3.2)
Soybeans	10	1.9-3.8/(.75-1.5)
Wheat	4	4.0-6.0/(1.5-2.5)

Table 1.6 SCIC Establishment benefit density chart (plants/square metre)

Crop	*Not Established	*Choice	*Established
Barley	Less than 84	84-132	132 +
Canaryseed	Less than 84	84-120	120 +
Canola (Hybrid)	Less than 14	14-48	48 +
Canola (open pollinated)	Less than 30	30-48	48+
Chickpea (Desi)	Less than 30	30-42	42 +
Chickpea (Kabuli)	Less than 18	18-30	30 +
Coriander	Less than 66	66-102	102 +
Faba beans	Less than 12	12-18	18 +
Field Peas	Less than 30	30-42	42 +
Flax	Less than 120	120-179	179 +
Dry Beans	Less than 12	12-24	24 +
Lentils	Less than 36	36-60	60 +
Mustard	Less than 30	30-48	48 +
Oats	Less than 84	84-132	132 +
Rye (Fall)	Less than 54	54-75	75 +
Rye (Spring)	Less than 84	84-132	132 +
Soybeans	Less than 30	30-42	42 +
Sunflower	Less than 4	4-6	6 +
Triticale	Less than 84	84-132	132 +
CPS Wheat	Less than 84	84-132	132 +
ESRS Wheat	Less than 84	84-132	132 +
HRS Wheat	Less than 84	84-132	132 +
SWS Wheat	Less than 84	84-132	132 +
Durum Wheat	Less than 84	84-132	132 +
Winter Wheat	Less than 54	54-75	75 +

**Based on the Saskatchewan Ministry of Agriculture recommended plant densities and seeding rates.*
Courtesy of: Saskatchewan Crop Insurance Corporation

Seed Treatments

A seed treatment is formulated as a fungicide, insecticide, or a biological and is used to help reduce seedling mortality from disease, insects or environmental conditions. These formulations can be systemic or contact depending on the treatment used. Systemic products are required to control pathogens present in the embryo, whereas contact or protectant products are suitable for other seed-borne and soil-borne pathogens. Fungal seed treatments work to protect the seed in two ways: controlling fungal pathogens present either on the seed surface or carried internally in the seed; and controlling fungal pathogens present in the soil or sprouting on organic matter in the soil.

It is important that the seed is treated to the label recommendations, as good coverage can help with improved emergence and stronger root systems. Some systemic seed treatments have a residual effect and can last up to three weeks. This prolonged control can sometimes reduce the need for an insecticide application and overall can help with reducing an economic impact. The degree of control with seed treatment depends on active ingredients, rate, suspected pests present, environmental conditions and application coverage.

There are a few steps to ensure good coverage when using a seed treatment. A few things to consider are:

Seed Cleaning

- Cleaning the seed can help increase the coverage as it removes unwanted chaff, dust, and unwanted seeds.

Test the Seed

- Seed testing can determine if the seed is disease free and can also identify what diseases may be present. Seed tests can be completed ahead of time at a lab. Seed borne diseases found during a seed test will help determine a proper fungicide seed treatment. Fungicide seed treatments protect seed viability and inhibit the invasion of fungal pathogens.

Seed Temperature

- A seed that is cool in temperature can result in poor coverage; as the treatment can flash freeze when it touches the seed. The cooler the seed the longer it will take the treatment to adhere to the seed, which can reduce the overall coverage. Furthermore, as the seed warms up, moisture can be drawn out of the seed, resulting in rewetting.

Once the pre-steps have been met, treatment may begin. It is important to follow the label recommendations, adequately mix the product and have the treater accurately calibrated. Treating seed may require alterations as different seed size, seed temperature and humidity can all alter seed coating. Once everything is to spec, have the treatment mix through an auger or screw type-mixer. It is important to run the auger two thirds full to get the best possible coverage. Full coverage of the product is essential to ensure proper protection and is especially important for contact fungicides. Treating seed ensures that the crop gets off to a good start. Keep in mind that seed treatments will not "cure" a poor seed lot that has high proportions of dead, damaged or infested seed.

Figure 1.18 Good seed treatment cover vs. bad

Figure 1.19 Good pulse seed treatment cover vs. bad

Figure 1.20 Complete (left) vs. partial (right) seed treatment on peas

Figure 1.21 Complete (left) vs. partial (right) seed treatment on wheat

Plant Stand Counts with Various Row Spacing

If you are scouting multiple fields with different row spacing, using a hoola hoop or square foot ruler may be challenging to calculate accurate counts. An alternate way to do plant stand counts is to count the plants down the row and use some basic math to calculate average plants/ft² or plants/m².

Counting Plants/ft²

When establishing an average plant population for such a small representative area, you want to count a larger area and take the average. For example, counting down three feet of a seed row and then averaging out to one square foot.

Take wheat for example:

Step 1: Establish Row Spacing.

- In this example we will use nine-inch spacing

Step 2: Count the number of plants down three feet of a seeded row.

- 45 plants in three feet

Step 3: Calculate the average number of plants per square foot.

- Plants in 3 feet / 3 feet / row spacing (inches) x 12 inches
- 45 plants/ 3 feet / 9-inch row spacing x 12 inches

= 20 plants/ft²

Counting Plants/m²

Step 1: Establish Row Spacing in centimetres.

- In this example we will use 10-inch spacing which is 25 cm

Step 2: Use a metre stick and count the seedlings in one metre of a seeded row.

- 28 plants counted in one metre of a row

Step 3: Calculate the average number of plants per square metre.

$$\text{Plants/m}^2 = \frac{\text{Plants per metre of row x 100}}{\text{Row Spacing (cm)}}$$

- 28 plants x 100/25cm

= 112 plants/m²

m²/10.76= ft²

Section 2: Soils, Fertility & Nodulation

Nutrient Uptake and Removal by Field Crops

The ranges for nutrient uptake and removal values given in the tables below are general estimates. They are based on typical nutrient concentrations and good growing conditions in Western Canada. Actual uptake and removal will vary from year to year based on crop yield, variety, soil fertility and environmental conditions.

Soil properties and climatic conditions affect crop nutrient uptake. Low soil moisture, poor aeration from compaction or excessive moisture, low soil temperatures, nutrient imbalances and other factors may restrict uptake of plant nutrients.

Crop fertility requirements will differ from these nutrient removal values. Crops are unable to extract all plant available nutrients from the soil and fertilizer as they are not 100 per cent efficient. For any given yield, the total nutrient supply in the soil will be somewhat greater than the amount removed by the crop. Soil tests will provide the best information on soil nutrient supply and recommendations for fertilizer application.

Nutrient contents in harvested grain or straw are extremely variable due to variations in harvesting methods (cutting height, method of collection, timing of harvest, etc.). It is highly recommended that nutrient analysis of representative subsamples of the harvested material be conducted for more accurate estimates of nutrient removal.

To view webinars on how to interpret soil tests, please visit *@AGSaskWebinars on YouTube*.

Table 2.1 Nutrient removal and uptake in crops in Western Canada

		Macronutrients				**Micronutrients[A]**		
		Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulphur	Boron	Copper	Zinc
Crop	**Nutrient**	**lb. nutrient per bushel grain produced**				**lb. nutrient per bushel grain produced**		
Cereals								
Barley	Uptake	1.25-1.53	0.50-0.61	0.2-1.46	0.15-0.18	-	-	-
	Removal	0.89	0.39	0.28	0.07	0.009	0.029	0.152
Corn (grain)	Uptake	1.38-1.68	0.57-0.69	1.16-1.41	0.13-0.16	-	-	-
	Removal	0.8	0.38	0.25	0.06	0.015	0.012	0.089
Durum	Uptake	1.83-2.25	0.67-0.75	1.5-2	0.2-0.25	-	-	-
	Removal	1.81	0.53	0.34	0.12	0.01	0.048	0.189
Oats	Uptake	0.96-1.17	0.36-0.45	1.31-1.60	0.12-0.14	-	-	-
	Removal	0.71	0.27	0.18	0.06	0.006	0.022	0.097
Wheat	Uptake	1.90-2.33	0.73-0.88	1.63-2.0	0.2-0.25	-	-	-
	Removal	1.46	0.53	0.27	0.1	0.007	0.033	0.191
Winter wheat	Uptake	1.22-1.48	0.54-0.68	1.28-1.56	0.18-0.22	-	-	-
**Limited data*	Removal	1.97	0.59	0.74	0.12	0.055	0.044	0.163
Oilseeds								
Canola	Uptake	2.86-3.51	1.31-1.63	2.09-2.54	0.49-0.60	-	-	-
	Removal	1.87	0.78	0.38	0.22	0.058	0.024	0.184
Flax	Uptake	2.58-3.17	0.75-0.92	1.63-2.0	0.50-0.63	-	-	-
	Removal	2.14	0.7	0.47	0.14	0.093	0.061	0.228
Mustard[B]	Uptake	N/A	N/A	N/A	N/A	-	-	-
**Limited data*	Removal	2.46	0.83	0.48	0.64	0.051	0.028	0.219
Sunflower	Uptake	1.34-1.64	0.46-0.56	0.66-0.88	0.16-0.18	-	-	-
	Removal	0.96-1.18	0.28-0.36	0.22-0.26	0.08-0.10	-	-	-
Pulses								
Chickpeas	Uptake	2.18	0.67	0.87	0.15	-	-	-
	Removal	2.62	0.54	0.81	0.12	0.052	0.055	0.198

Table 2.2 Nutrient removal and uptake in crops in Western Canada continued

		Macronutrients				Micronutrients[A]		
		Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulphur	Boron	Copper	Zinc
Crop	**Nutrient**	**lb. nutrient per bushel grain produced**				**lb. nutrient per bushel grain produced**		
Dry bean	Uptake	2.80	0.83	2.37	0.20	-	-	-
	Removal	2.13	0.66	1	0.12	0.071	0.049	0.166
Faba bean	Uptake	5.14-6.28	1.78-2.16	4.58-5.60	0.24-0.30	-	-	-
	Removal	3.07	0.74	0.94	0.13	0.064	0.072	0.298
Lentil	Uptake	2.73-3.37	0.73-0.90	2.3-2.8	0.27-0.33	-	-	-
	Removal	2.69	0.62	0.71	0.13	0.046	0.055	0.233
Pea	Uptake	2.76-3.36	0.76-0.92	2.46-3.0	0.22-0.28	-	-	-
	Removal	1.94	0.51	0.64	0.11	0.052	0.042	0.201
Soybeans	Uptake	5.25-5.80	0.88-1.00	4.13-4.40	0.34-0.35	-	-	-
	Removal	3.1	0.87	1.15	0.2	0.174	0.075	0.22

[A] Micronutrient removal values from U of S Nutrient Removal Calculator study (2020-2022)

[B] Mustard uptake data not available. Please consult canola values for best estimate expected for mustard uptake.

Note: This table was created by combining information from the Canadian Fertilizer Institute as well as values from the Durum Production Manual revising the crop nutrient uptake and removal guidelines for Western Canada (ADF 2119018) performed during 2020-2022. Please note that uptake and removal values will differ with changes in environmental conditions, such as drought.

Guidelines for Safe Rates of Seed-Placed Fertilizer

The following are considered to be approximate guidelines for safe rates of urea (46-0-0) and ESN® nitrogen applications with the seed in cereal grains, canola and flax. All rates are in pounds of actual nitrogen per acre. Width of spread varies with air flow, soil type, seed, opener wear, moisture level, amount of residue and other soil conditions.

Seedbed Utilization (SBU) is the amount of the seedbed over which the fertilizer has been spread. SBU is a reflection of the relative concentration of fertilizer.

SBU (%) = (Width of the spread ÷ row spacing) x 100.

For example: If the seeding implement has a nine-inch spacing and spreads seed and fertilizer over two inches, the SBU would be (2 ÷ 9) x 100 = 22%.

Table 2.3 Safe Nitrogen Rates When Applying Urea

UREA*	**1 inch spread (disc or knife)**			**2 inch spread(spoon or hoe)**			**3 inch spread (sweep)**		
Row Spacing	6 in	9 in	12 in	6 in	9 in	12 in	6 in	9 in	12 in
Seedbed Utilization	17%	11%	8%	33%	22%	17%	50%	33%	25%
Cereal Grains									
Light (sandy loam)	20	15	15	30	25	20	40	30	25
Medium (loam to clay loam)	30	25	20	40	35	30	50	40	35
Heavy (clay to heavy clay)	35	30	30	50	40	35	60	50	40
Canola & Flax									
Light (sandy loam)	10	5	0	20	15	10	30	20	15
Medium (loam to clay loam)	15	10	5	30	20	15	40	30	20
Heavy (clay to heavy clay)	20	15	10	40	30	20	50	40	30

**Rates are given in pounds per acre. Courtesy of: Agrium Advanced Technologies*

Note: When soil moisture is at less than field capacity, values should be reduced by 50 per cent to minimize the risk of damage to the seeded crop.

Table 2.4 Safe Nitrogen Rates When Applying ESN®

ESN®*	1 inch spread (disc or knife)			2 inch spread (spoon or hoe))			3 inch spread		
Row Spacing	6 in	9 in	12 in	6 in	9 in	12 in	6 in	9 in	12 in
Seedbed Utilization	17%	11%	8%	33%	22%	17%	50%	33%	25%
Cereal Grains									
Light (sandy loam)	40-60	30-45	30-45	60-90	50-75	40-60	80-120	60-90	50-75
Medium (loam to clay loam)	60-90	50-75	40-60	80-120	70-105	60-90	100-150	80-120	70-105
Heavy (clay to heavy clay)	80-120	70-105	60-90	100-150	80-120	70-105	120-180	100-150	80-120
Canola & Flax									
Light (sandy loam)	20-30	10-15	0	40-60	30-45	20-30	60-90	40-60	30-45
Medium (loam to clay loam)	30-45	20-30	10-15	60-90	40-60	30-45	80-120	60-90	40-60
Heavy (clay to heavy clay)	40-60	30-45	20-30	80-120	60-90	40-60	100-150	80-120	60-90

** Pounds per acre of nitrogen as ESN® shown to be safe when applied with the seed. Based on 2x-3x the safe rate of urea and Ammonium Sulphate. Check the local seed-safe rates for your geography and crop.*
Courtesy of: Canadian Fertilizer Institute and Agrium

Note: Recommended rates are based on proper handling of ESN®. *** N rates in the table are in addition to the N in safe rates of seed-placed phosphorus fertilizer (monoammonium phosphate).

Table 2.5 Maximum Safe Rate of Actual Seed-Placed Phosphorus Fertilizer

	Actual P_2O_5 (lbs/ac)*		
	Row Spacing (assuming 1 inch spread)		
	9-inch	10-inch	12-inch
Seedbed Utilization	**11%**	**10%**	**8%**
Cereals	50	45	37
Canola	25	22	19
Canaryseed, Pinto bean	30	27	22
Flax, Pea, Forages (Alfalfa, Bromegrass)	15	13	11
Faba bean	40	36	30
Lentil, Mustard, Chickpea	20	18	15

*Note: This table is simply a guideline, environmental conditions and soil texture should be considered when formulating a fertilizer application. When soil moisture is at less than field capacity, values should be reduced by 50 per cent to minimize the risk of damage to the seeded crop. * Narrow openers at wider spacings, dry conditions and sandy textured soil will increase the risk of injury and reduce the amount of fertilizer that can safely be placed in the seed row. Recommendations are based on the use of monoammonium phosphate (NH4H2PO4) MAP. Diammonium phosphate ((NH4)2 HPO4) DAP is much more toxic to seedlings than monoammonium phosphate and should be used with caution when placed with the seed.*
Courtesy of: Canadian Fertilizer Institute

Potassium

The total pounds of phosphate (P_2O_5) plus pounds of potassium (K_2O) should not exceed the maximum safe rate of seed-placed phosphate. This applies under good to excellent moisture conditions.

Many areas in Saskatchewan have potassium rich parent material containing significant quantities of plant available potassium. Potassium fertilizer requirements may be less in these soils. However, potassium deficient soils do exist and the best way to determine nutrient levels is through soil testing.

Potassium behaves differently in different soil textures. Soils with high clay or organic matter content can adsorb and exchange more potassium, allowing more of the nutrient to be available to the crop. While potassium is a relatively immobile nutrient in soil, it can be leached below the root zone in sandy soils due to their inherent low cation exchange capacity. Organic soils may also be prone to potassium leaching from the root zone over time as potassium binds weakly to organic matter.

Potassium chloride is a widely used source of potassium fertilizer and may also be applied when chlorine is needed in a nutrient fertility plan. Chlorine is mobile in the soil and can be limiting in light-textured soils. Chloride can be measured in both a tissue test and soil test.

Sulphur

Sulphate-sulphur is the plant-available form of sulphur (S) and should be used to correct S deficiencies. When ammonium-sulphate fertilizer is placed with the seed, add the pounds of nitrogen (N) from the ammonium-sulphate to the pounds of N from other nitrogen fertilizers being placed with the seed. The total N should not exceed the maximum safe rate of seed-placed nitrogen. This applies under good to excellent moisture conditions. Ammonium sulphate has a high salt effect. Rates of seed-placed ammonium sulphate near or above 20 lb. S/ac. have shown to reduce the emergence of canola under some conditions.

Types of Fertilizer

Table 2.6 Nutrient plant available forms, functions and common fertilizer formulations

Macronutrients (N, P and K)			
Nutrient	**Plant Available Form**	**Function Within Plants**	**Common Fertilizer Formulations ($N-P_2O_5-K_2O-S$) and State**
Nitrogen (N)	NH_4^+ (ammonium) NO_3^- (Nitrate)	Main component of proteins, chlorophyll and plant hormones	46-0-0-0 (Urea. Granular) 82-0-0-0 (Anhydrous Ammonia. Gaseous) 28-0-0-0 (Urea Ammonium Nitrate or UAN. Liquid)
Phosphorus (P_2O_5)	$H_2PO_4^-$ (orthophosphate) HPO_4^{2-} (Secondary orthophosphate) *form availability is pH dependent)	DNA, RNA, enzymes, ATP Photosynthesis, sugar transformation into starches	11-52-0-0 or 12-58-0-0 (Monoammonium phosphate. Granular) 10-34-0-0 (Ammonium polyphosphate. Liquid)
Potassium (K^+)	K^+	Enzyme activation, osmosis, turgor generation, membrane electrical potential regulation, pH homeostasis Very abundant in plant cell functions	0-0-60-0 or 0-0-62-0 (Potassium Chloride. Granular) 0-0-50-18 (Potassium Sulphate. Granular) 13-0-44-0 (Potassium Nitrate. Granular)
Secondary Nutrients (S, Ca and Mg)			
Nutrient	**Plant Available Form**	**Function Within Plants**	**Common Fertilizer Formulations (N-P2O5-K2O-S) and State**
Sulphur (SO_4^{2-})	SO_4^{2-}	Chlorophyll formation, protein production, oil synthesis, enzyme activation	21-0-0-24 or 20.5-0-0-24 (Ammonium Sulphate. Granular) 0-0-0-90 or 0-0-0-95 (Elemental Sulphur. Granular) 15-0-0-20 (Ammonium Thiosulphate. Liquid)
Calcium (Ca2+)	Ca^{2+}	Cell wall structure, regulates cations and anions within the cells	Lime, Gypsum, Calcium Chloride
Magnesium (Mg^{2+})	Mg^{2+}	Chlorophyll component and involved in chlorophyll synthesis	Dolomitic Limestone

Table 2.6 Nutrient plant available forms, functions and common fertilizer formulations continued

Micronutrients			
Nutrient	**Plant Available Form**	**Function Within Plants**	**Common Fertilizer Formulations and State**
Boron ($H_3BO_4^{3-}$)	$H_3BO_4^{3-}$	Cell division, flowering, reproduction and root elongation	Sodium Tetraborate, Borax, Sodium Pentaborate
Chloride (Cl^-)	Cl^-	Cell division, water regulation, enzyme activity	0-0-60-0 (Potassium Chloride. Granular)
Copper (Cu^{2+})	Cu^{2+}	Assists in chlorophyll formation, an enzyme activator for chlorophyll	Copper Sulphate, Copper Oxy-Sulphate, Chelated EDTA
Iron (Fe^{3+})	Fe^{3+}	Involved in chlorophyll, protein synthesis and respiration	Ferrous Sulphate, Ferric Sulphate

Table 2.7 Typical nutrient contents in liquid swine effluent and fresh cattle pen manure samples in Sask.

	Liquid Swine Manure (feeder hogs) Pounds per thousand gallons	**Fresh Cattle Penning Manure (with straw bedding)** % on dry weight basis
Nitrogen (N)	15 - 50	0.5 - 1.5
Phosphorus (P)	1 - 20	0.5 - 1.5
Potassium (K)	8 - 20	0.8 - 1.5
Sulphur (S)	0.1 - 3	0.08 - 0.15
Copper (Cu)	0.05 - 0.5	0.01
Manganese (Mn)	0.05 - 0.5	0.02
Zinc (Zn)	0.05 - 1.0	0.02
Boron (B)	0.01	0.005

Note: multiply P by 2.3 to convert to P_2O_5; multiply K by 1.2 to convert to K_2O. Research by J. Schoenau, 1998-00

Table 2.8 Per cent of plant macronutrients available in hog manure over time

	Year 1 %	**Year 2 %**	**Year 3 %**	**3 Year Total %**
Nitrogen - Mineral	100	0	0	100
Nitrogen - Organic	25	12	6	43
Phosphorus	50	12	6	68
Potassium	90	0	0	90
Sulphur	50	0	0	50

Safe Rates of Application

The safe rate for manure application varies depending on the crop being grown. Selecting a rate that aligns with the crop's nutrient demand and expected nutrient removal over time is essential. To determine the appropriate application rate, both manure and soil testing should be conducted to ensure optimal nutrient management.

Application Methods

When considering manure application methods for liquid manure, it is recommended to use technologies that inject or incorporate the manure into the soil rather than applying it on the soil surface. Surface application can lead to higher nutrient losses, while injecting or incorporating manure helps retain nutrients, reduces runoff, and minimizes odor. However, it's important to note that injection methods have been linked to increased nitrous oxide production, so careful management is essential to balance these factors. Manure application should be done when temperatures are conducive to incorporating the manure and should not be applied to frozen soil.

For solid manures, the focus should be on uniform spreading. Vertical beater manure spreaders tend to have improved distribution and uniformity. Solid manure decomposes slowly so nutrients are released/mineralized over several years.

Challenges of using manure as a fertilizer

- Variability and often low nutrient content, which may not align with the specific nutrient requirements of the crop and creates a challenge to economically transport the manure for use.
- Some nutrients in manure are in organic form and are not readily available to plants. These nutrients must go through a decomposition process (mineralization) to be converted to inorganic forms available for plant uptake.
- Excessive application and repeated application in the same field, can lead to problems such as lodging, haying off, salt loading, and toxicity.
- There is a risk of nutrient loading and pollution from losses due to leaching, runoff, erosion and gaseous escape.
- Sodium present in manure can negatively affect soil structure by decreasing aggregation through particle dispersion.

Benefits of using manure as a fertilizer

- Effective for supplying plant nutrients and adding organic matter to agricultural soils for multiple years.
- Increased crop growth from manure application results in increased plant residues, decaying roots and litter being returned to the soil and therefore an increase in soil organic matter.
- Increases in soil organic matter from manure applications result in improved water holding capacity, infiltration, water-stable aggregation, nutrient cycling, increased microbial activity, decreased bulk density and surface crusting, thus improving soil health/quality.

Table 2.9 Comparison of solid manures and liquid effluents

	Pros	Cons
Solid manures	High organic matter. Improve soil tilth. Very effective in decreasing soil density. Increases pore spaces for air, water, and root exploration. Long term soil builder.	Slow availability of nutrients. Potential source of surface and groundwater contamination.
Liquid effluents	High nutrient availability in the year of application.	Low organic matter. Potential source of surface and groundwater contamination.

Properties of liquid swine effluent:

- 5-50 lb. of total N per 1,000 gallons.
- 30-90 per cent of the total N is ammonium (plant available).
- An estimated 20-30 per cent organic N is mineralized to plant available forms in the year of application.
- 1-20 lb. of total P/1,000 gallons.
- 10-50 per cent of P is readily soluble.
- 8 to 20 lb. K/1,000 gallons.
- K is readily available to crops.

Properties of feedlot cattle manure:

- 10-20 per cent release of available N in year of application is typical for feedlot cattle manure.

Manure Nutrient Analysis

While there are tables that describe the typical nutrient contents of different manure sources, laboratory analysis of a representative sample of the manure will give the best indication of the nutrient value of the manure. These results will be useful in determining appropriate rates of application for the crop to be grown. There is high variability in nutrient content even within a single storage unit, so consider taking several sub-samples and combine for analysis to achieve an average nutrient level.

Many commercial laboratories on the prairies offer manure analysis and crop recommendation packages based on an analysis of manure and soil samples. Note that residual organic fraction nutrients are not picked up in a regular soil test so one must be careful about nutrient loading. Good record-keeping for each field is important.

Example Calculation:

A farmer grew a canola crop that produced 3,000 kg per ha of canola seed yield. Part 1: Calculate how much P (kg P/ ha) is removed in the canola seed harvest given a canola seed phosphorus concentration of 0.8 per cent P. Part 2: Calculate how much solid cattle manure (kg manure/ ha) would need to be applied to replace the phosphorus removed from this field in the canola seed harvest given a manure P concentration of one per cent P.

Part 1 Answer: 3000 kg canola seed yield per ha x 0.008 (P content of canola seed expressed as decimal) = 24 kg P per ha removed in canola seed harvest.

Part 2 Answer: 24 kg P per ha / .01 (P content in manure expressed as decimal) = 2,400 kg of cattle manure per ha or 2.4 tonnes per ha of cattle manure.

Collecting Manure Samples

Liquid Manure

Liquid manure is typically agitated to mix solids that settle at or near the bottom of the unit to create a more homogeneous mixture. However, even after agitation, the mixture will not be completely homogenous. Collecting and combining multiple samples throughout the pump-out process will give the best composite sample of liquid manure.

Take a PVC pipe and insert it directly into the slurry. Hold one hand on the top of the pipe to create a suction. Remove the pipe and place the sample into a clean plastic pail. Take five total samples and thoroughly mix the substrate. Once the slurry is mixed, it can be placed into a small (1/2 to 1 litre) screw top container, label the container with the date, time, pit name, manure type and farm name for lab identification. Once the sample is correctly labeled and lid secured, place the container into a plastic bag to help prevent any leakage.

Solid Manure

Use a fork or spade and sample portions of the manure pile that you know will be spread, taking samples from multiple depths. Solid manure can be taken from multiple locations including manure piles, housing areas, or directly from the manure spreader before application. Since only a small amount of manure is analyzed, it is difficult to gather a true representative sample. Mixing multiple samples should help obtain a representative sample. Manitoba Agriculture mentions the cone and quarter method to sample solid manure which is described as follows:

1. Combine all of the solid manure samples on a plastic sheet or cement pad and mix thoroughly, chopping large chunks with a fork or spade.
2. Divide the well-mixed manure into four portions.
3. Discard two of the four portions.
4. Combine the remaining two portions and mix .
5. Repeat steps 2, 3 and 4 until the remaining sample is small enough to subsample and send for analysis.

General Guidelines for Manure Sample Collection

1. Before sampling, check with the lab you're submitting to if they have specific sampling instructions to be followed or information that should be included with your sample.
2. Properly record information to go with your sample including farm name, date, site/storage information and manure source.
3. Leave some extra space in the sample container to allow for gases to accumulate.
4. Ensure the sample container is sealed properly and use a secondary container to prevent leakage.
5. Keep samples cool until they are sent for analysis. If sampling during warm weather, place samples in a cooler with ice packs to avoid impacting sample integrity.
6. Similarly with soil samples, try and ship samples at the beginning of the week so that they are delivered as quickly as possible. Samples should not sit in warm storage for very long. If necessary, freeze samples ahead of time before shipping if delays are expected.

Source: Manitoba Agriculture, Properties of Manure, 2015

Additional resources for managing manure as a fertilizer:

- *Manure as a Fertilizer, Saskatchewan Ministry of Agriculture*
- *Properties of Manure, Manitoba Agriculture (2015)*

Saline, Alkaline or Sodic Soils

There are many terms used to describe soils in Saskatchewan, many of which get confused or are interchanged incorrectly.

Saline soil refers to soil that contains soluble salts that reduce plant growth. In Saskatchewan, the most common salts are sulphates of magnesium and sodium (however, there are a few areas with chloride salts). Calcium sulphate salts may also be present in saline soils, but their impact is limited due to the low solubility of gypsum ($CaSO_4$). Salinity reduces plant growth by affecting the osmotic potential of the soil solution. Water flows from low salt concentration to high salt concentration. Roots mainly uptake water by osmosis and in normal conditions have a higher salt concentration than the soil water. This is why in a saline soil the osmotic movement of water to roots is inhibited.

Reclamation of saline soil can only be achieved with a combination of drainage and leaching of the salts below the root zone, often not realistic for producers that have smaller pockets of unproductive saline land. However, it is sometimes appropriate to convert the land to perennial forage and improve productivity. Perennial forages will also help lower a high water table, allowing for potential downward movement of soluble salts from rainfall. This will temporarily reduce the severity of the salinity until the water table rises again. Soil salinity should be viewed not as a soil problem, but as a water problem. There is no additive you can apply to your land to reverse the effects of salinity. Consult an agronomist or other specialist if you have questions about managing your soil.

Alkaline soils refer to soil that has a pH range greater than seven. Many soils in Saskatchewan have a higher pH and are considered alkaline.

Sodic (alkali) soils are affected by an excess of exchangeable sodium and have a pH over 8.5. There are limited true sodic soils in Saskatchewan. Sodic soils can exist on their own or can be present in saline soils at the same time. These are called saline-sodic soils and have different management and reclamation requirements. Consulting an agronomist, crops extension specialist, or an agri-environmental specialist would be beneficial to achieve successful management.

Soil Electrical Conductivity

Simply put, electrical conductivity measures the ability of ions in solution to carry an electrical current over a specified distance. The electrical conductivity of a soil is in direct proportion to the concentration of soluble salts and inversely proportional to the measurement distance. The measurements are either made in a 1:1 suspension of soil:water (this method is most often used) or in an extract of a saturated soil paste. The units for soil electrical conductivity are milliSiemens/cm (mS/cm) or decisiemens/metre (dS/m) which are equivalent to each other in value and are corrected to 25 C. Soils with an electrical conductivity value of >4 dS m^{-1} (measured from a saturated soil extract) are classified as saline.

In the field, soil salinity and the variability of salinity can be measured with a tool called an EM38. However, the interpretation of EM38 readings can be more difficult due to the fact that they are influenced by temperature, moisture and soil texture. The units of measure for the EM38 are milliSiemens/metre. It can measure salinity in the 0 – 120 cm depth when in the vertical position and 0 - 60 cm depth in the horizontal position.

Source: Les Henry Handbook of Soil and Water
Source: Digging into Canadian Soils

Table 2.10 Soil Salinity Ratings

E.C. (dS/m or mS/cm)*	Degree of salinity	Hazard for crop growth	Plant Response
0-2	Non-saline	Very low	Negligible
2-4	Slightly saline	Low	Restricted yield of sensitive crops
4-8	Moderately saline	Medium	Restricted yield of many crops
8-16	Severely saline	High	Only a few tolerant crops yield satisfactorily
>16	Very severely saline	Very high	Only a few salt tolerant forage grasses grow satisfactorily
***as determined by the saturated paste extract method**			

Source: Manitoba Soil Fertility Guide

Table 2.11 Crop Tolerance to Soil Salinity

E.C. Saturation Extract (dS/m or mS/cm)	Annual Crops	Forage Crops
0-4	Bean Faba bean Peas Corn Potatoes	Red Clover Alsike Timothy
4-8	Barley Fall Rye Winter Wheat Spring Wheat Oats Flax Canola	Birdsfoot trefoil Sweet Clover Smooth Bromegrass Alfalfa Intermediate wheatgrass Crested wheatgrass Meadow fescue Reed Canary
8-16	Land best suited to forage crops	Tall wheatgrass Slender wheatgrass Russian wildrye

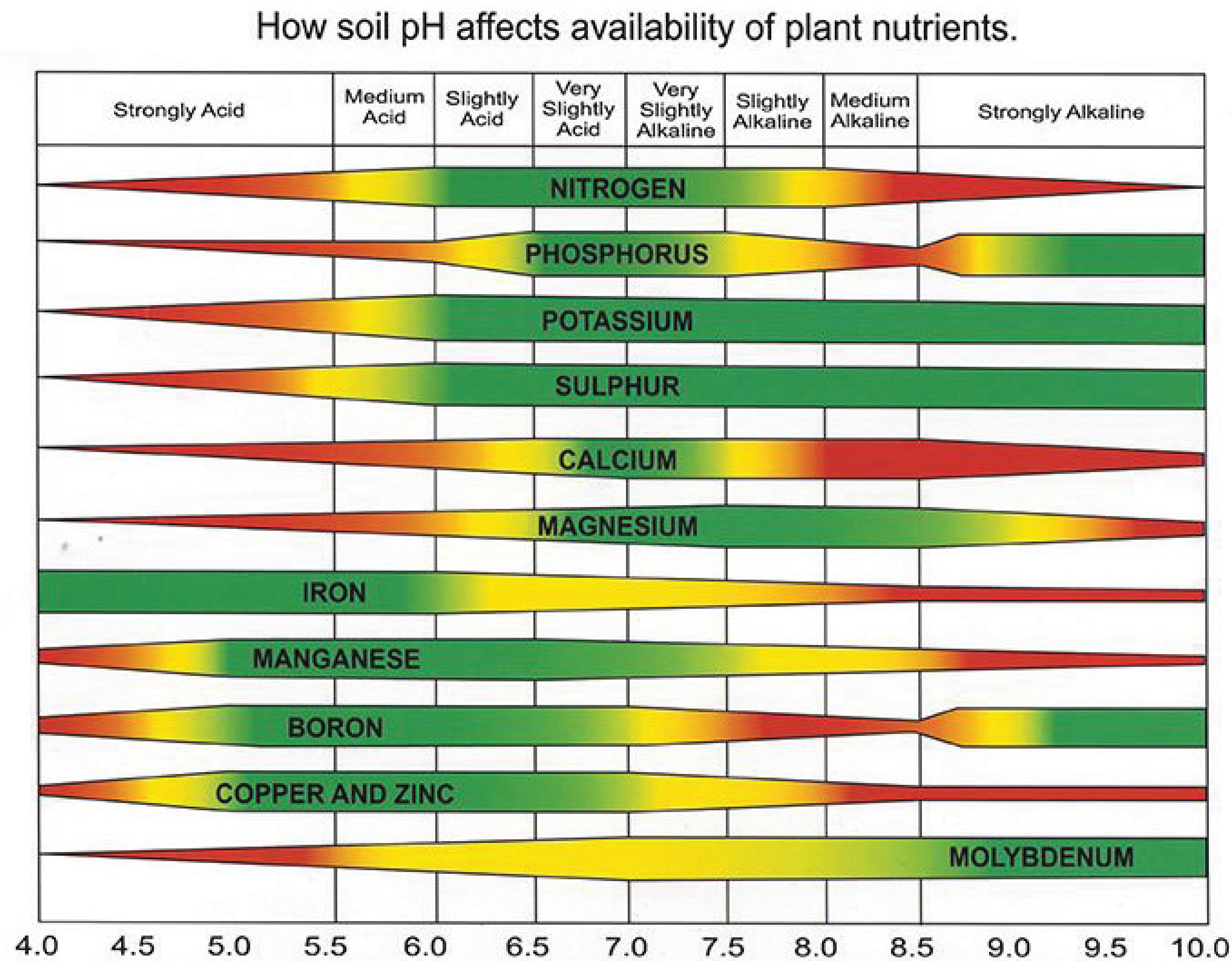
Note that there can be varietal differences to salinity tolerance.

More information can be found on the Nature and Management of Salt-Affected Land In Saskatchewan online at *https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/nature-and-management-of-salt-affected-land-in-saskatchewan*

The Importance of Soil pH

Soil pH is a measurement of the acidity or alkalinity of a soil. It is often an overlooked factor in a plant's overall health. Soil pH regulates the relative availability of nutrients in the soil, influences the chemical reactions of soil nutrients and can have an impact on herbicide effectiveness and carryover.

Figure 2.1 pH affects availability of plant nutrients



Adapted from Brady and Weil, 2007.

Besides affecting the relative availability of certain nutrients, acidic soil conditions also:

- Inhibit the growth of Rhizobium needed for effective nodulation by legumes.
- Cause herbicides in the imidazolinone family to break down more slowly thereby increasing the risk of carryover injury.

Strongly alkaline soils will reduce the relative availability of phosphorus, calcium, iron, manganese, copper and zinc.

- There will also be greater losses of urea fertilizer to volatilization.
- Seed-placed urea damage is more likely to occur.
- Herbicide carryover damage is more likely to occur from herbicides in the sulfonylureas and triazine family as breakdown of these herbicides is slowed.

Essential Nutrients

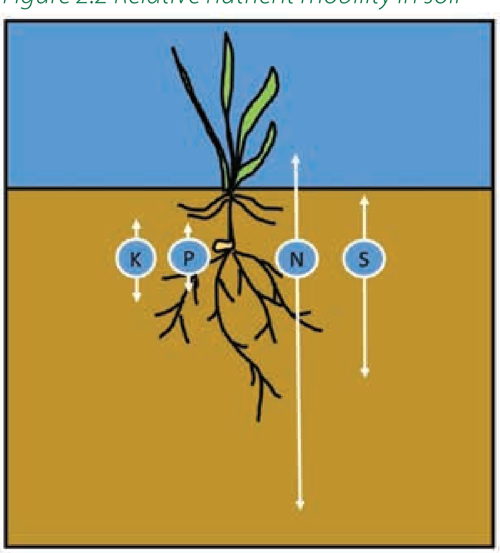
Diagnosing micronutrient deficiencies in the field by assessing crop symptoms is difficult, even for trained agronomists. Multiple signs of deficiencies should be observed before recommending a micronutrient application. A combination of crop symptoms in the field, tissue tests, soil tests, test strips, cropping history and other techniques can be used to confirm micronutrient deficiencies and economic yield responses. Take soil and plant tissue samples from the affected and unaffected areas within the same field for a complete comparative analysis. This service is available from most soil testing laboratories. Call the laboratory for sampling details for a complete comparative test.

Table 2.12 Essential nutrients, mobility, and deficiency symptoms.

Nutrient	Macro/ Micro	Uptake Form	Mobility in Plant	Mobility in Soil	Deficiencies Appear First In
Carbon	Macro	CO_2 from atmosphere, HCO_3^-			
Hydrogen	Macro	H+, OH^-, H_2O			
Oxygen	Macro	O_2			
Nitrogen	Macro	NO_3^-, NH_4^+	Mobile	Mobile as NO_3^-, immobile as NH_4^+	Older leaves
Phosphorus	Macro	HPO_4^{2-}, $H_2PO_4^-$	Somewhat mobile	Immobile	Older leaves
Potassium	Macro	K+	Very mobile	Somewhat mobile	Older leaves
Sulphur	Macro	SO_4^-	Immobile	Mobile	Young/new leaves
Calcium	Macro	Ca^{2+}	Immobile	Somewhat mobile	Young/new leaves
Magnesium	Macro	Mg^{2+}	Somewhat mobile	Immobile	Older leaves
Boron	Micro	H_3BO_3, BO_3^-	Immobile	Very mobile	Young/new leaves
Copper	Micro	Cu^{2+}	Immobile	Immobile	Young/new leaves
Iron	Micro	Fe^{2+}, Fe^{3+}	Immobile	Immobile	Young/new leaves
Manganese	Micro	Mn^{2+}	Immobile	Mobile	Young/new leaves
Zinc	Micro	Zn^{2+}	Immobile	Immobile	Young/new leaves
Molybdenum	Micro	MoO_4^-	Mobile	Somewhat mobile	Entire plant
Chlorine	Micro	Cl^-	Mobile	Mobile	Young/new leaves
Nickel	Micro	Ni^{2+}	Mobile	Somewhat mobile	

***Disclaimer: This table is for a general guideline only. When conducting diagnostics, several factors need to be considered before concluding the cause of crop symptoms.*

Figure 2.2 Relative nutrient mobility in soil



Note: Nitrogen is shown also leaving the soil upwards. This is due to possible volatilization.

Nodulation and Nitrogen Fixation Field Assessment Guide

To ensure that proper nodulation does occur, legumes need to be inoculated with the appropriate inoculant at the time of planting. As the table below indicates, each species of legume has its own inoculant that must be used. Using the wrong inoculant on the wrong crop will result in incomplete inoculation and poor to nonexistent nodulation.

Table 2.13 Rhizobium species required for legume crops

Crop	Rhizobium
Alfalfa, sweet clover	*Rhizobium meliloti*
Chickpea	*Rhizobium ciceri*
Clover	*Rhizobium trifolii*
Dry bean	*Rhizobium phaseoli*
Fenugreek	*Rhizobium spp. Strain RGFU1*
Pea, lentil, faba bean, chickling vetch	*Rhizobium leguminosarum*
Soybean	*Bradyrhizobium japonicum*

Improper handling or misapplication of inoculants will also result in inoculant failure. If poor nodulation has occurred, investigate what inoculant was used and how it was stored and applied.

Inoculants are sensitive to granular fertilizer therefore, banding fertilizer to the side and/or below the seed is recommended. Inoculant should never be tank blended with fertilizer. Inoculants are also sensitive to some seed-applied fungicides. Check the labels of both the inoculant and seed treatment for compatibility. When using a combination of fungicide and inoculant, apply the fungicide to the seed first, allow it to dry, and then apply the inoculant just before seeding.

Inoculants are available in liquid, peat-based, and granular formulations.

Liquid-based products offer convenience and better control of application rate, compared to other forms. However, the rhizobia in these formulations are more susceptible to damage from environmental extremes and direct contact with seed treatments. If treated seed is planted immediately into a moist seedbed, liquid formulations perform well.

Peat-based formulations are more durable and less prone to damage from direct contact with seed treatments compared to liquid formulations, but care must still be taken. Some peat-based powder inoculants require the use of a sticker. Adhesion to the seed can be enhanced if the seed is slightly damp during application.

Granular formulations offer ease of application and are less affected by environmental stress and seed-applied fungicides than other inoculant forms. These formulations should be applied in the seed row. Granular inoculants remove the risk of incompatibility with seed treatments, but care must still be taken to minimize risk of desiccation.

Adapted from Sask Pulse Growers

Accurate field measurements of nitrogen fixation responses to inoculation with *Rhizobium* are often difficult, undependable and expensive. However, nitrogen fixation can be estimated through an assessment of nodulation and plant growth characteristics.

This guide will help growers and agronomists learn how to assess nodulation and nitrogen fixing potential in the field.

Nodule Assessment Timing

Nodulation assessments should be done during **early flowering**. Nodule formation begins approximately 14 days after crop emergence, but certain environmental conditions such as cool soil temperatures, pH extremes, extremely dry conditions and salinity can slow nodulation formation for up to three to four weeks.

Legume crops can be ranked according to their estimated ability to fix nitrogen: alfalfa > clover > faba bean > pea > chickling vetch > chickpea > lentil > soybean > lupin> dry bean.

Nodule numbers and nitrogen fixation rates generally are at a maximum during early-to-mid flowering. After flowering, nodule efficiency is reduced and they begin to shut down.

Assessment Procedure

To assess the nodulation and nitrogen fixation potential of a legume crop, select five areas that are typical of that field at early flowering. Follow the steps listed below in each of the five areas:

- Evaluate plant growth and vigour of the area according to the assessment codes shown below.
- With a shovel, carefully dig up a minimum of two plants per area. Do not pull plants out of the soil as nodules are delicately attached to roots and can be easily lost.
- Carefully examine plant roots to assess the nodules. Depending on the soil type and condition, this may require gently agitating the roots in water.
- Assess the overall nodulation by comparing the calculated scores to those provided for the three categories in the assessment guide.
- No nodules OR white or green nodules.

Assessment Codes

1. Plant and growth vigour

Assess colour and overall health of the plant:

- Plants are green and vigorous 5
- Plants are green and relatively small 3
- Plants are slightly chlorotic (yellow) 2
- Plants are very chlorotic (yellow) 1

Poor nitrogen fixation can cause nitrogen deficiency symptoms such as yellowing of the leaves at the base of the plant prior to flowering and poor plant development.

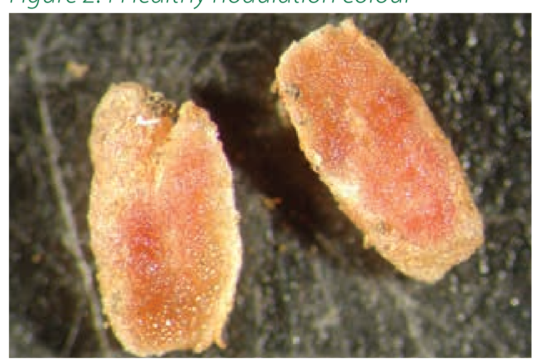
Nitrogen fixation efficiency can be estimated with nodule colour and the number of nodule clusters present. Carefully slice open the nodules. The strong pink colour of the nodules is caused by the presence of leghemoglobin, which must be present for active nitrogen fixation. If a nodule is brown, white or green it is considered non-effective.

2. Colour and abundance

- Greater than five clusters of pink pigmented nodules 5
- Three to five cluster groups of mostly pink nodules 3
- Less than three clusters of nodules OR white or green nodules 1
- No nodules OR white or green nodules 0

Figure 2.3 Faba beans in flower

Figure 2.4 Healthy nodulation colour



3. Nodule position

- Both crown and lateral nodulation 3
- Mostly crown nodulation only 2
- Mostly lateral nodulation only 1

Crown nodulation is predominantly observed when seed is inoculated. Lateral nodulation is prevalent when native *Rhizobia* species exist in the soil or when granular inoculants are used. The crown region of a plant is generally the area of soil surrounding the seed. The approximate size of this region varies according to the crop.

Figure 2.5 Poor nodulation (left) and abundant nodulation on plant roots (centre and right)

Table 2.14 Total nodulation score

11-13	Effective Nodulation	Numerous nodules that have good fixing nitrogen potential.
7-10	Effective Nodulation	Nodules present with limited nitrogen fixing potential.
1-6	Poor Nodulation	Few nodules present with very little to no nitrogen fixation potential.

In the field, a healthy plant does not always reflect effective nodulation and active nitrogen fixation. Localized soil environments, particularly with variations in soil nitrogen, may stimulate vigorous growth of the plant. Such situations are only apparent when the plants are dug up and examined for the presence of active nitrogen-fixing nodules.

Saskatchewan Soil Information System

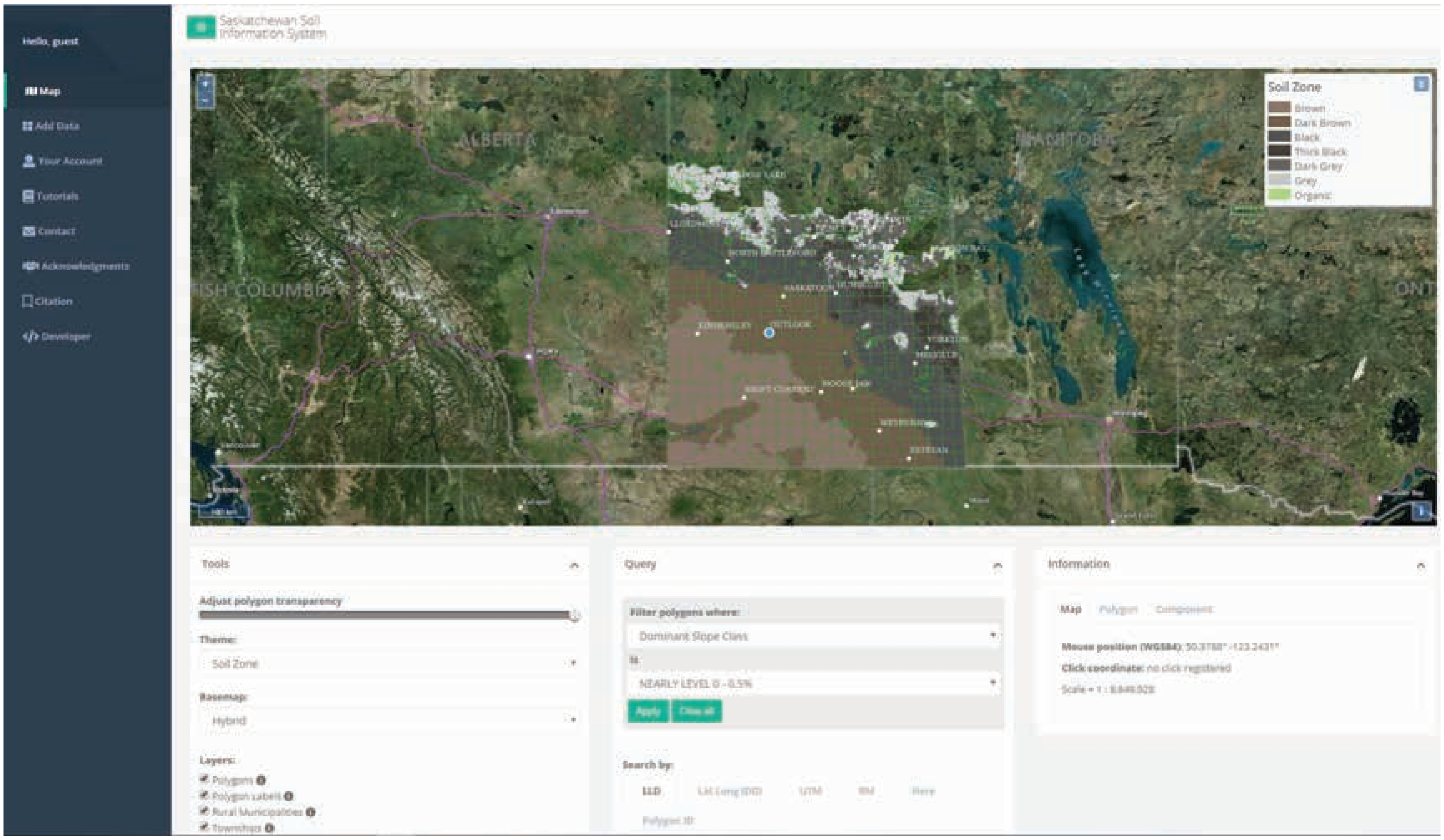
The Saskatchewan Soil Information System (SKSIS) is an interactive digital soil map evolved from the original Canadian Soil Survey Reports. The creation of this digital soil map has made soil information easily accessible to the public. You can learn about important soil and landscape characteristics by searching this database. When you type in the location details of the area you're interested in, the website automatically zooms to that area.

From there you can toggle through different map layers and see information like soil pH, soil texture, salinity, agricultural capability, slope class, stoniness and many other important soil and landscape characteristics. It is an important tool in interpreting soil tests results and developing management plans.

How to use Saskatchewan Soil Information System (SKSIS)- A digital soil map tool

1. Access SKSIS at http://sksis.usask.ca (Figure 2.6)

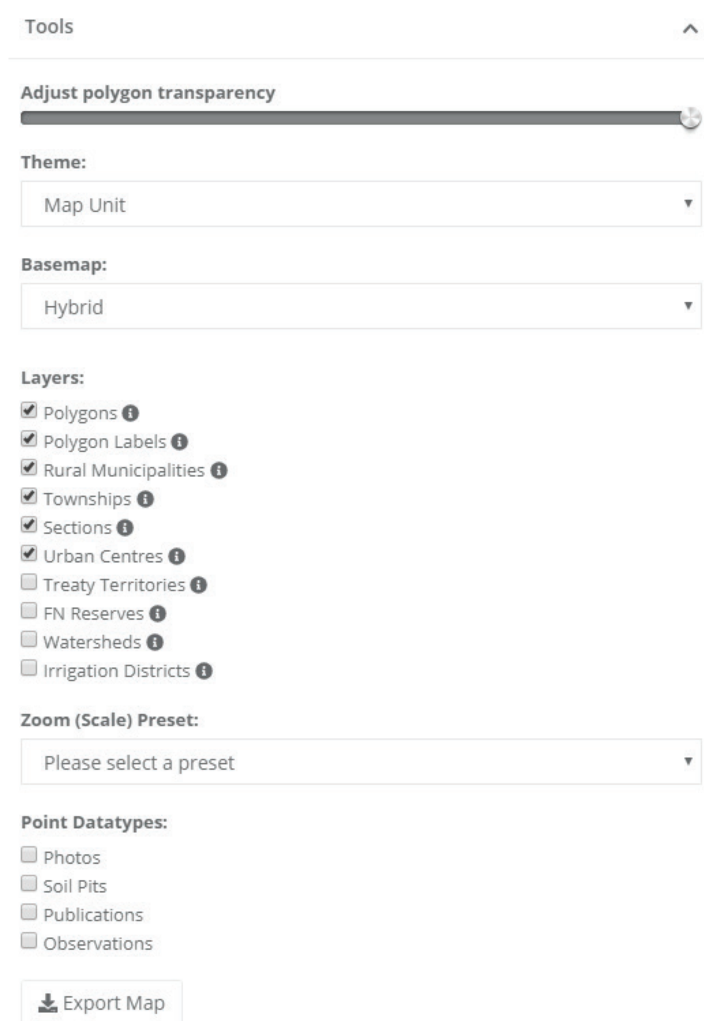
Figure 2.6 Starting page of SKSIS



Courtesy of: SKSIS

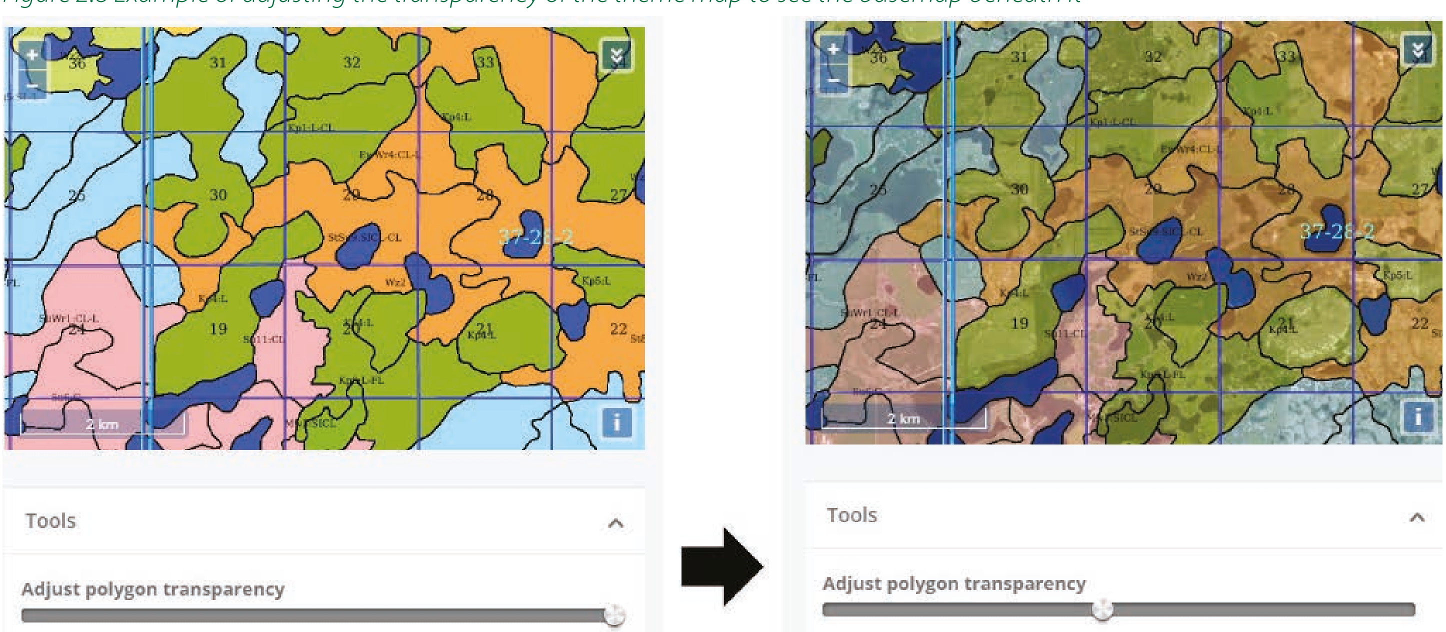
2. **First, you want to define what information you're looking for. Go to the "Tools" section. (Figure 2.7)**
   - **Theme** refers to the soil information displayed by SKSIS polygons. Select "Map Unit." This is the soil survey code for the soil association and series, that describes the soil classes, parent material and texture found in the polygon. The other themes ("Soil Zone", "Ag Capability" and "Soil Texture") can be used to visually compare two or more areas by one metric (i.e. seeing soil texture change over a certain area).
   - **Basemap** refers to the map underlying the SKSIS information. It can be changed depending on what information you would like to see. Selecting "Hybrid" gives an aerial image with road and RM information.
   - Adjust the polygon transparency by dragging the knob along the slider. This makes the theme map transparent so you can see the basemap beneath the SKSIS polygons (Figure 2.8).
   - Leave the sections: "Layers", "Zoom Preset" and "Point Datatypes" as is unless you're looking for something specific.

Figure 2.7 Tools box showing the transparency adjustment, theme and basemap



Courtesy of: SKSIS

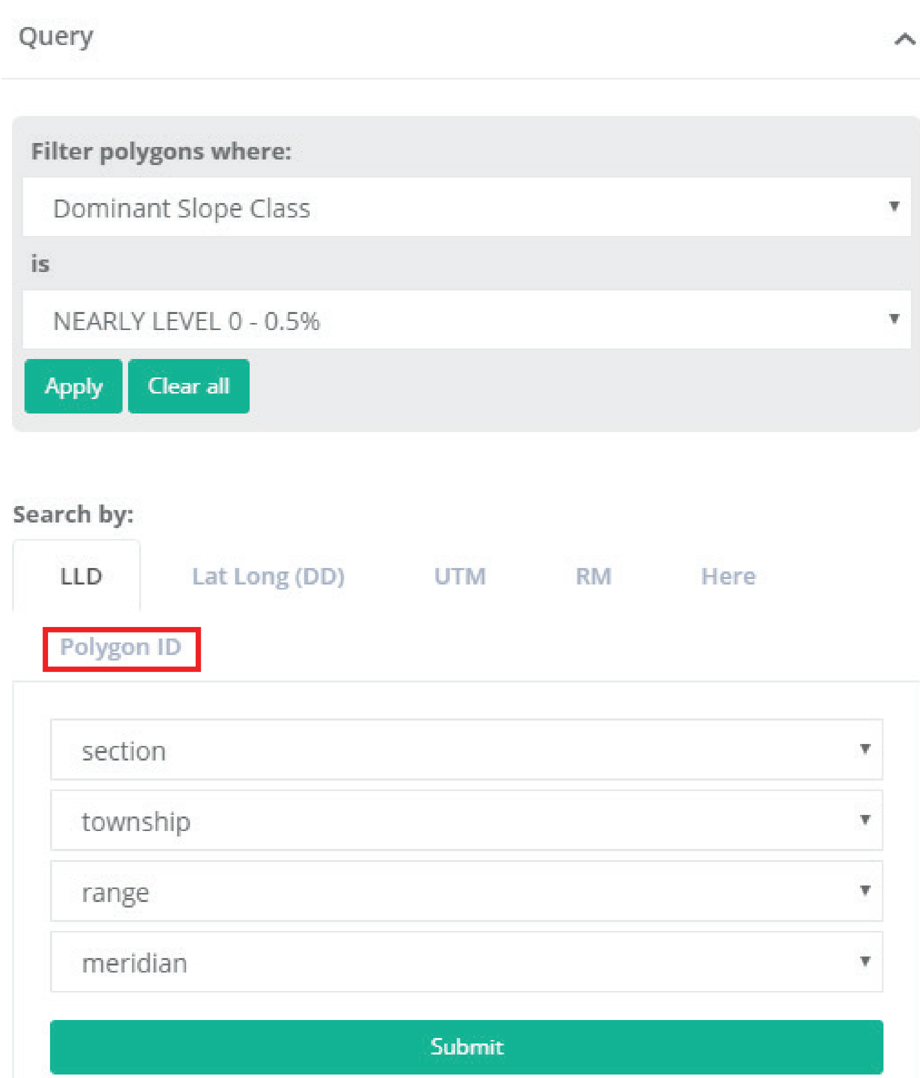
Figure 2.8 Example of adjusting the transparency of the theme map to see the basemap beneath it



Courtesy of: SKSIS

3. **Under the "Query" section, you can search by filtering out specific soils criteria or by using location details.**
   - Go to the **Polygon ID** section and enter in your preferred location details. This will automatically zoom to the area you're interested in (LLD, UTM, RM etc.) (Figure 2.9).

Figure 2.9 Query section showing the "Filter" tab, where you can search by specific soils criteria and the "Search by" tab, where you can search by location details



Courtesy of: SKSIS

4. **Once the map has zoomed into the area you are interested in, place a point on the map by clicking on the specific area.**
   - Under "Information: Polygon", (Figure 2.10) the soil map unit information can be found, this tab describes the soil characteristics of the polygon you clicked inside (Figure 2.9).

Figure 2.10 Information box showing soils information of the polygon selected.

Courtesy of: SKSIS

How to Interpret Polygon Information

1. **Stoniness is an estimation of the average severity of stoniness in a polygon. Severity classes are rated zero through four.**

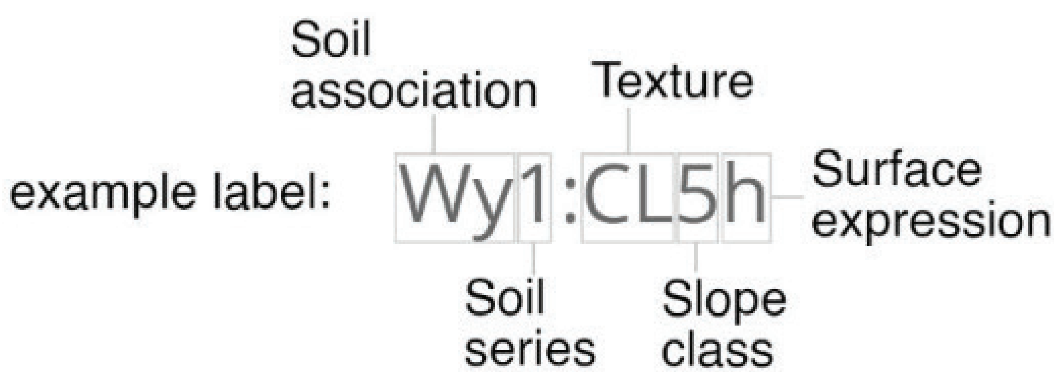
Table 2.15 Stone classes and descriptions

Symbol	Description
S0	Non stony
S1	Slightly stony-stones seldom hinder cultivation. Light clearing is occasionally required.
S2	Moderately stony-stones are a moderate hindrance to cultivation. Annual clearing is usually required.
S3	Very stony-stones cause serious hindrance to cultivation. Sufficient stones to require clearing on an annual basis.
S4	Excessively stony-stones prohibit cultivation or make clearing a major task. Cultivation is usually severely hindered, even after regular, heavy clearing.
U	Unclassified.

Courtesy of: Canadian Soil Information Service (CANSIS)

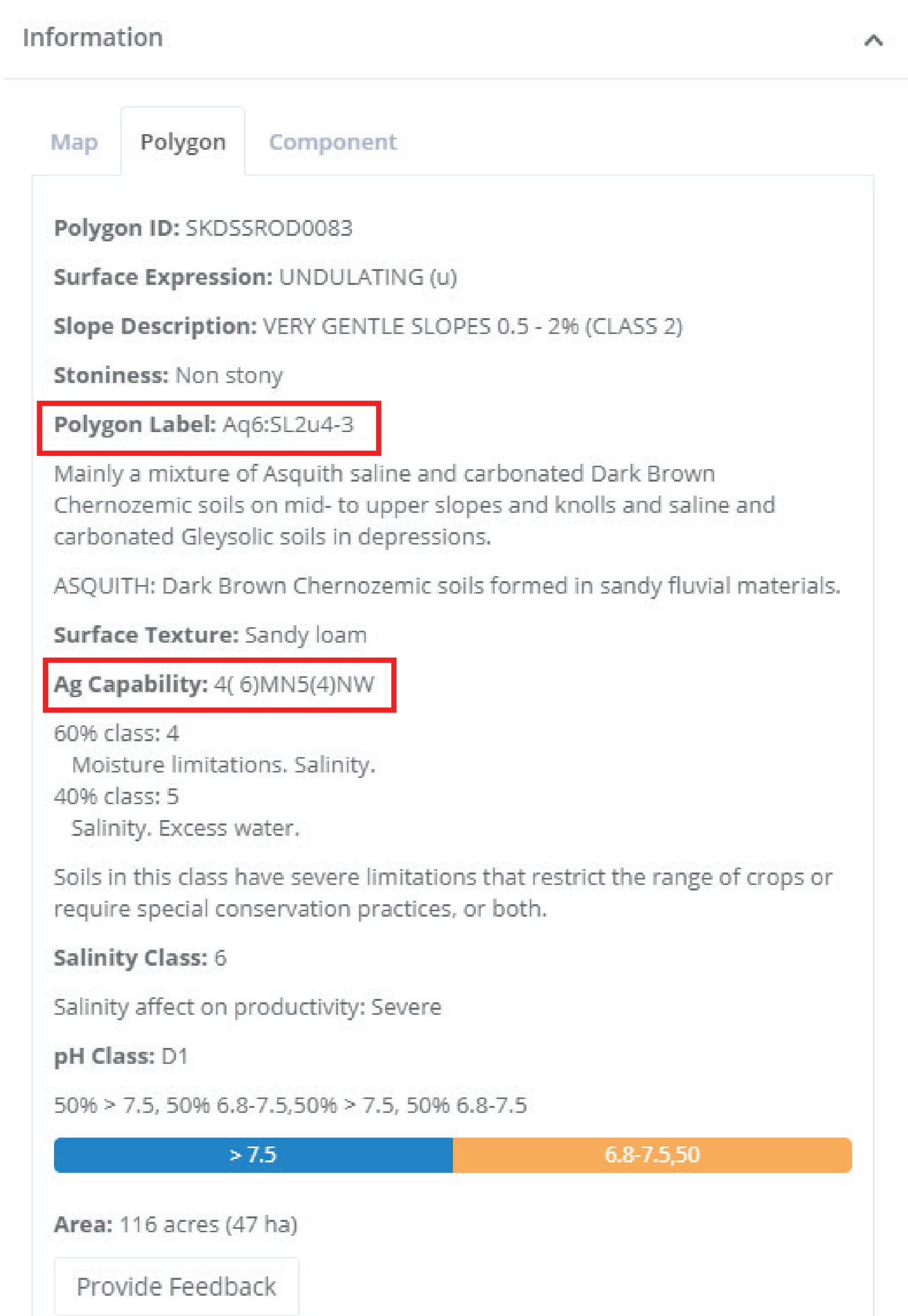
2. **The polygon label is a string of code that describes the soil association, soil series, soil texture, stoniness, slope class, surface expression and slope length. Beneath the polygon label is a detailed breakdown of the label (Figure 2.11).**

Figure 2.11 Polygon label with description (stoniness not depicted)



Courtesy of: (CANSIS)

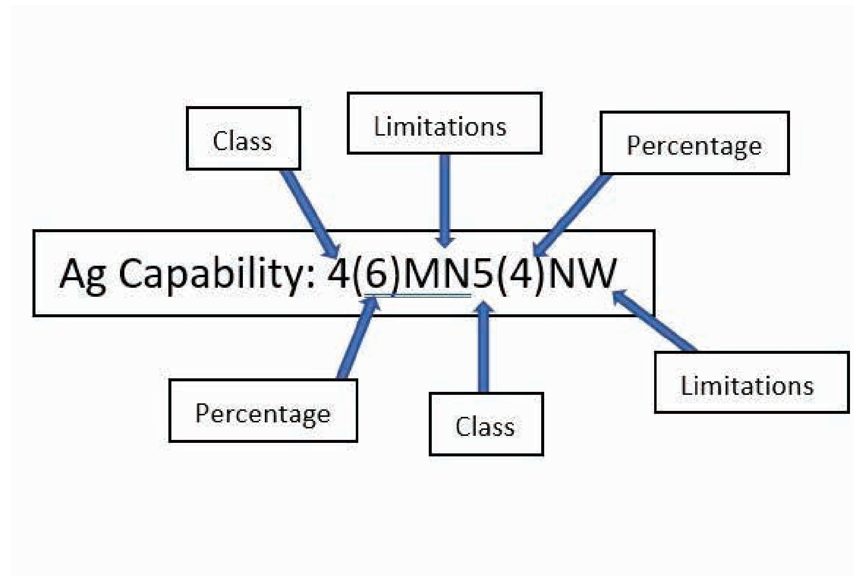
Figure 2.12 Detailed breakdown of soil information from the polygon label



Courtesy of: SKSIS

The **Ag Capability** section provides a string of text that describes the full agricultural capability rating. This label identifies the capability class, polygon percentage and specific limitations. The string from figure 2.12 is described below and on the following page as an example. The class number refers to the degree of the limitation and are numbered one through seven. The percentage describes the percentage of the area that is affected by the limitation. Limitation specifics are broken down into capability subclasses (kind of limitation). Details on subclasses can be viewed by clicking in the information icon below the listed Ag Capability. (Figure 2.13).

Figure 2.13 Ag capacity label showing the class, percentage and limitation



Courtesy of: SKSIS

Ag Capability explained in more detail. Showing the percentage of each class in the polygon selected and describing its agricultural limitations.

Ag Capability: 4(6)MN5(4)NW

60% class: 4
Moisture limitations. Salinity.

40% class: 5
Salinity. Excess water.

Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both.

Courtesy of: SKSIS

Table 2.16 Agriculture capability classes

CLASS 1	Soils in this class have **no significant limitations** in use for crops.
CLASS 2	Soils in this class have **moderate limitations** that restrict the range of crops or require moderate conservation practices.
CLASS 3	Soils in this class have **moderately severe limitations** that restrict the range of crops or require special conservation practices.
CLASS 4	Soils in this class have **severe limitations** that restrict the range of crops or require special conservation practices, or both.
CLASS 5	Soils in this class have **very severe limitations** that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.
CLASS 6	Soils in this class are **capable of producing native forage crops only**. Improvement practices are not feasible.
CLASS 7	Soils in this class have **no capability for arable agriculture or permanent pasture**.

Courtesy of: CANSIS

3. **The salinity class section gives a general classification of the salinity present in the soils and a description of the salinity effect on productivity.**

4. **The pH class indicates the relative acidity or alkalinity of the surface layer of the soil (10-20cm). The surface pH classes are indicated by a letter X, A, B, C, or D ranging from moderately acidic to alkaline (Table 2.16). The class is then broken down into the percentage of the surface area in each pH range.**

Table 2.17 Surface pH classes

pH Class	pH Range	Description
X	less than 5.5	Moderately acid
A	5.5 to 6.0	Slightly acid
B	6.1 to 6.7	Slightly acid to neutral
C	6.8 to 7.5	Neutral to slightly alkaline
D	greater than 7.5	Alkaline

Courtesy of: CANSIS

Survey information presented in SKSIS is available through the Canadian Soil Information Service (CanSIS). The original Soil Survey Reports can also be accessed through CanSIS; these reports are excellent resources for descriptions of local soil associations, geology, landforms, climate, and hydrology.

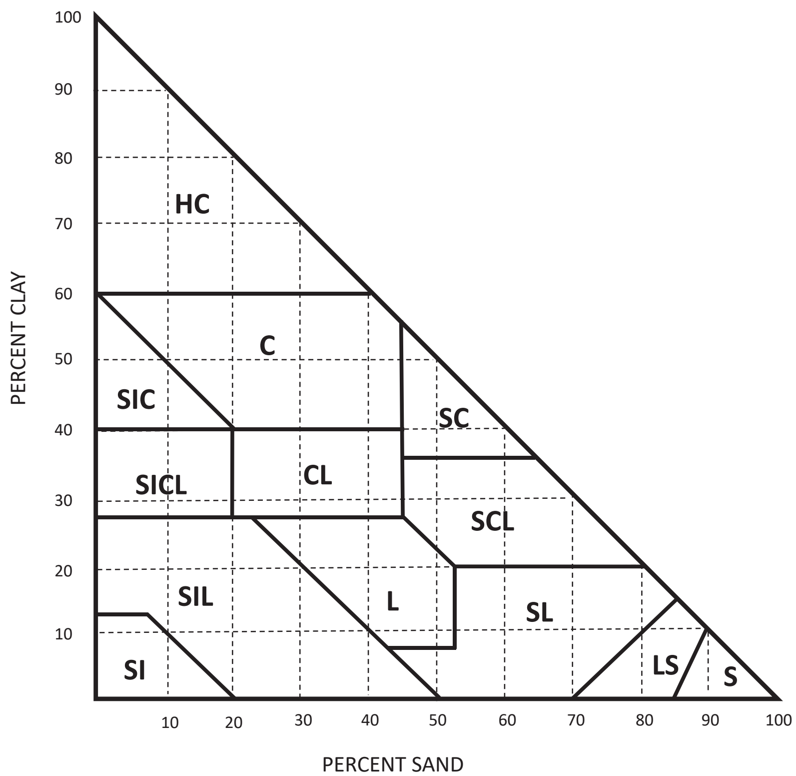
Reference-SKSIS Working Group. 2018. Saskatchewan Soil Information System-SKSIS. A. Bedard-Haughn, M. Bentham, P. Krug, K. Walters, U. Jamsrandorj, and J. Kiss, eds. [Online] Available: sksis.usask.ca [March 10, 2020].

Soil Texturing

Hand texturing is a tool you can use to get a fast and reliable texture reading of your soil. Soil textures can range from sand to slit to clay or a combination of any of these. A soil texture triangle depicts the many texture ranges of soil. The hand texturing flowchart (Figure 2.14) is a simple process or guide you can follow to determine the texture of your soil.

Figure 2.14 Soil texture triangle

Soil Texture Triangle



Adapted from the University of Saskatchewan

Surface Texture Groups	Soil Texture Classes
Coarse	CS - Coarse sand S - Sand FS - Fine sand LS - Loamy sand LFS - Loamy fine sand GS - Gravelly sand GLS - Gravelly loamy sand
Moderately Coarse	VL - Very fine sandy loam FL - Fine sandy loam SL - Sandy loam GSL - Gravelly sandy loam
Medium	L - Loam SI - Silt SIL - Silt Loam GL - Gravelly loam
Moderately Fine	CL - Clay loam SICL - Silty clay loam SCL - Sandy clay loam FCL - Fine sandy clay loam VCL - Very fine sandy clay loam
Fine	HC - Heavy clay C - Clay SIC - Silty clay SC - Sandy clay
Miscellaneous	
O U	Organic Unclassified

Figure 2.15 Hand texturing flow chart

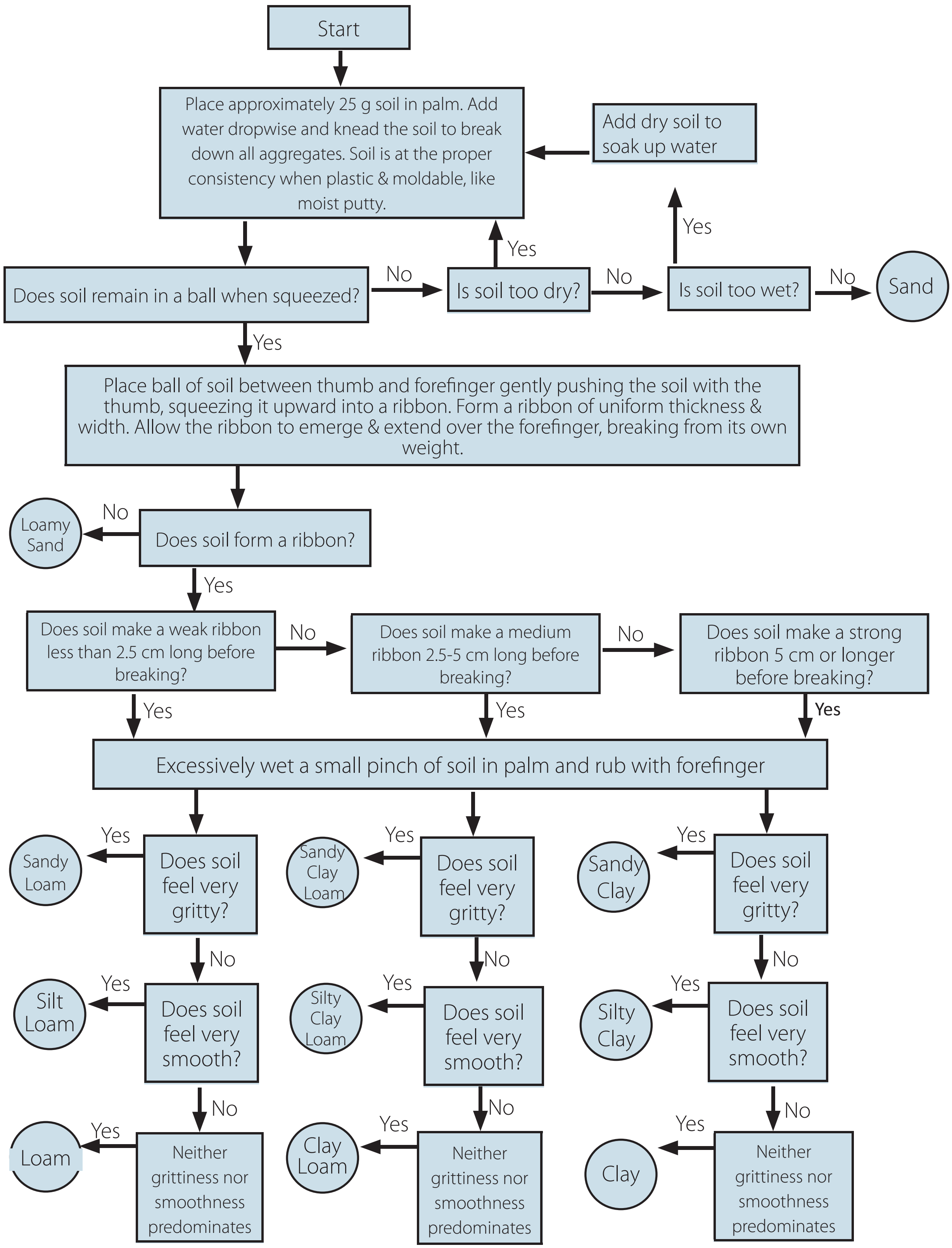


Figure 2.16 Steps for hand texturing soil

Figure A. Place approximately 25g of soil in palm.

Figure B. Soil should be moldable

Figure C. Does soil remain in a ball when squeezed?

Figure D. Does the soil form a ribbon?

Figure E. Measure the ribbon length to find category. Note: if it is close to 5cm choose the middle category rather than going up to the last category.

Figure F. Excessively wet a pinch of soil and feel for texture

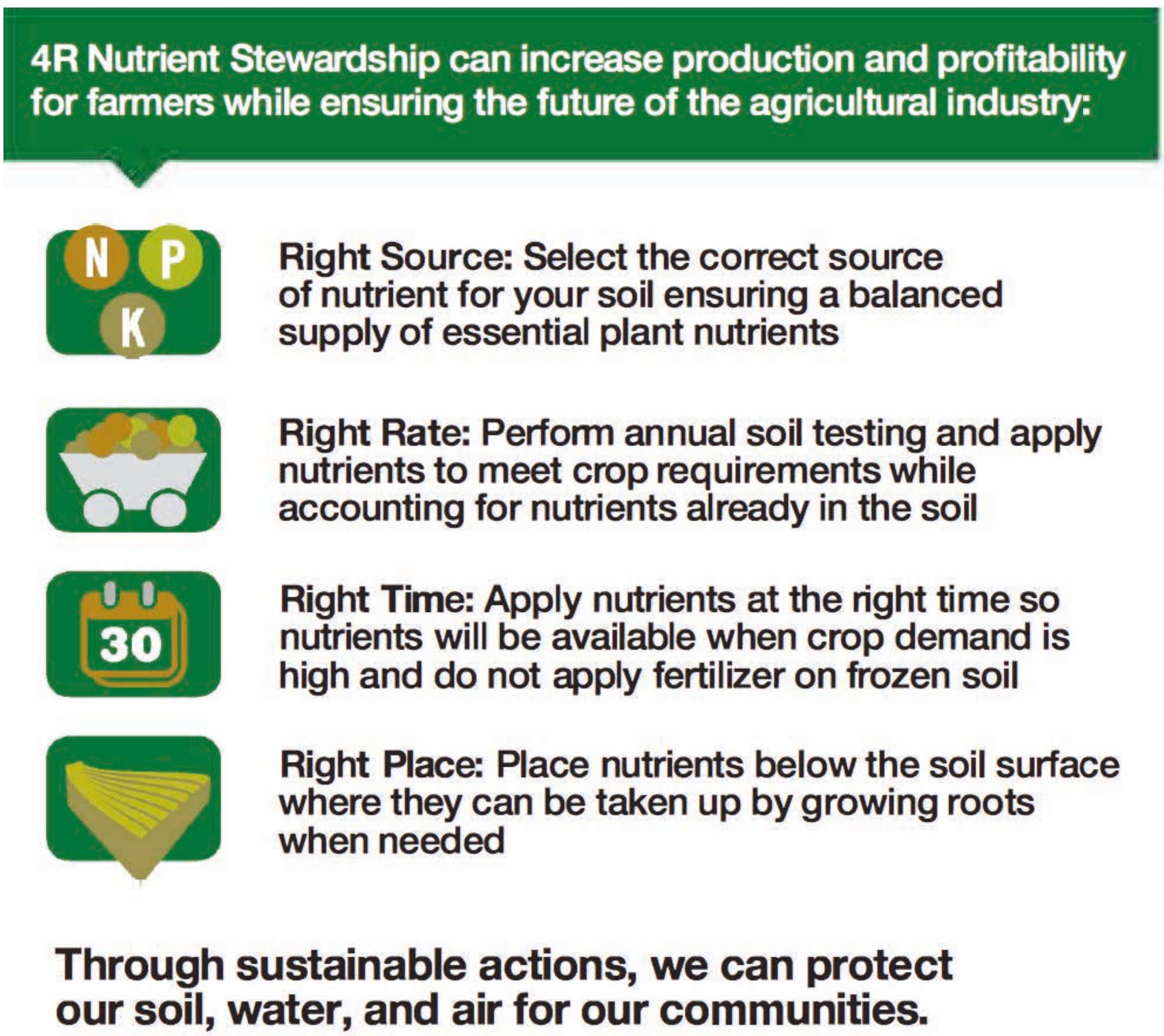
4R Nutrient Stewardship Designation

The 4R Nutrient Stewardship Program (Right Source @ Right Rate, Right Time, Right Place ®) provides a framework to achieve cropping system goals, increased production, increased farmer profitability, enhanced environmental protection and improved sustainability. 4R Nutrient Stewardship requires the implementation of best management practices (BMPs) that optimize the efficiency of fertilizer use. The goal of fertilizer BMPs is to match nutrient supply with crop requirements and to minimize nutrient losses. Selection of BMPs varies by location, and those chosen for a given farm are dependent on local soil and climatic conditions, crop, management conditions and other site specific factors. 4R Designation provides recognition for farmers who complete and apply 4R Nutrient Stewardship grower plans.

Minimize impact to the environment

Contribute to Canada's environmental goals by implementing 4R practices on farm. Retaining nutrients within a field's boundaries and in the crop rooting zone greatly reduces the amount that is not utilized by plants and escapes into the environment as pollution.

Figure 2.17 4R Nutrient Stewardship



Courtesy of: Fertilizer Canada

Figure 2.18 4R Designation

Step	Grower	Agronomist	Agri-Retailer	Fertilizer Canada
1. Education	Learn about 4R Nutrient Stewardship (e.g. via web, print, workshop, conference) and see if it makes sense.	Ensure credentials are in good standing: • P.Ag and/or CCA • 4R eLearning (overarching and region-specific courses)	Corporate decision to buy-in Internal and external marketing 4R training (overarching and region-specific courses)	Fertilizer Canada maintains and communicates recent, updated programs to retailer.
2. Planning	Meet with the agri-retailer to develop 4R consistent plan along with fertilizer recommendations	Develop retailer procedures for 4R programming: • Training • Manuals • Other items of relevance Independents may have flexibility while larger companies may need ISO-type procedures	Work with 4R agronomist to provide 4R training to staff, update credentials as required and build 4Rs into agronomy software Meet grower to make NPK 4R consistent plan with CCA or equivalent advisor	Provide online system for agri-retailer to register 4R acres as they are approved by 4R agronomist
3. Reporting	Consent to have 4R consistent plan	Review and sign-off of 4R grower plan Report acres to Fertilizer Canada	Attestation of 4R readiness via P.Ag, 4R Agronomist and 4R 'checklist' guidelines.	Keep directory of 4R agronomists.
4. Implementation	Implement the 4R consistent plan	Follow up with agri-retail CCAs and growers to check on progress	-	Register information on acres, eco districts and crops under 4R Protect confidentiality of grower/agri-retailer and keep data simple.
5. Recognition	Receive 4R signage and recognition	Build relationship with customer	Support grower 4R implementation and provide recognition	Promote 4R designated agri-retailers through promotional boxes and communication pieces: press releases, industry partners, internal newsletters, etc.
6. Review	Review progress with agri-retailer	End of season tune-up with 4R consistent plan and actual implementation	Review progress with grower	Publish annual report of compiled 4R acres by crop type and region

Adapted from: Fertilizer Canada

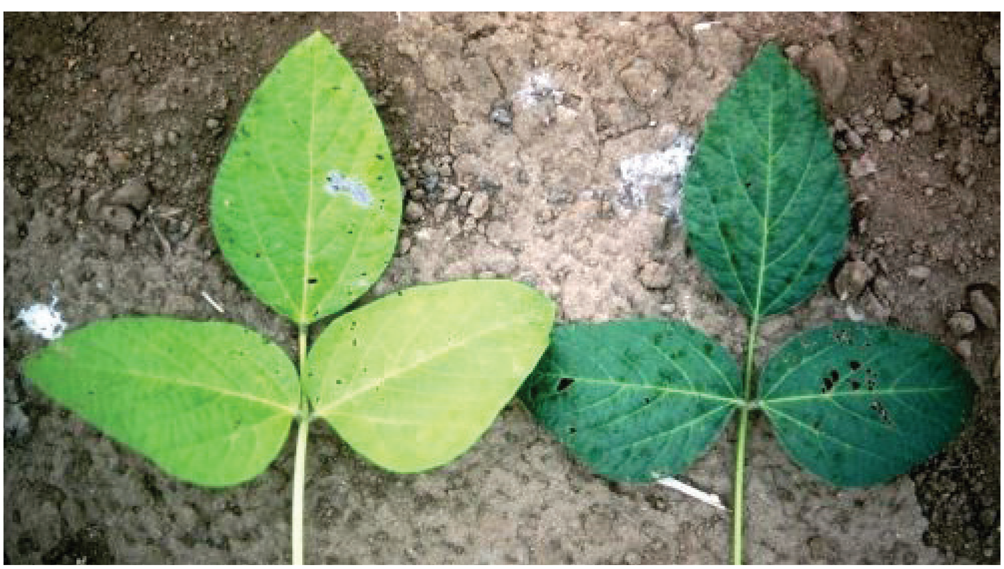
Nitrogen

Deficiency symptoms appear first on older leaves as light-green to yellow foliage, and then develop on younger plant parts as the conditions become more severe. Other symptoms include: stunted, spindly plants, less tillering in small grains, low protein content in seed and vegetative parts and fewer leaves. Nitrogen deficient plants will mature early with significantly reduced yield and quality.

Figure 2.19 Effect of starter N (UAN) in a no-till environment.
Left-no starter N, Right-starter N applied with the planter.

Courtesy of: The Fertilizer Institute

Figure 2.20 Nitrogen deficiency symptoms in soybean



Courtesy of: The Fertilizer Institute

Figure 2.21 Nitrogen deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.22 Nitrogen deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.23 Nitrogen deficiency symptoms in wheat

Courtesy of: The Fertilizer Institute

Figure 2.24 Nitrogen deficiency symptoms in barley

Courtesy of: The Fertilizer Institute

Figure 2.25 Nitrogen deficiency symptoms in mustard

Courtesy of: The Fertilizer Institute

Figure 2.26 Nitrogen deficiency symptoms in canola

Courtesy of: The Fertilizer Institute

Phosphorus

The first sign of a phosphorus shortage is an overall stunted plant. Leaf shapes may be distorted and tissue may be dark green in colour. With severe deficiency, dead areas may develop on leaves, fruit, and stems. Older leaves are affected before younger ones. Some plants, such as corn, may display a purple or reddish colour on the lower leaves and stems. This condition is associated with accumulation of sugars in P-deficient plants, especially during times of low temperature.

Figure 2.27 Phosphorus deficiency symptoms in chickpeas

Courtesy of: The Fertilizer Institute

Figure 2.28 Phosphorus deficiency in barley

Courtesy of: The Fertilizer Institute

Figure 2.29 Phosphorus deficiency in canola leaves

Courtesy of: The Fertilizer Institute

Figure 2.30 Canola with phosphorus (left side of photo) and canola without phosphorus (right side of photo)

Courtesy of: The Fertilizer Institute

Figure 2.31 Phosphorus deficiency in canola leaves

Figure 2.32 Phosphorus deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.33 Phosphorus deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.34 Phosphorus deficiency in corn

Courtesy of: The Fertilizer Institute

Potassium

One of the most common potassium deficiency symptoms is scorching or firing along leaf margins. Since potassium is mobile in the plant, deficiency symptoms appear on older leaves first. Potassium-deficient plants grow slowly and develop poor root systems. Stalks are weak and lodging is common. Seed and fruit are small and shriveled; crops show lower resistance to disease and moisture stress.

Figure 2.35 Potassium deficiency in corn

Courtesy of: The Fertilizer Institute

Figure 2.36 Potassium deficiency in soybeans

Courtesy of: The Fertilizer Institute

Figure 2.37 Potassium deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.38 Potassium deficiency in barley

Figure 2.39 Potassium deficiency in barley

Figure 2.40 Potassium deficiency in barley

Courtesy of: The Fertilizer Institute

Figure 2.41 Potassium deficiency in canola

Courtesy of: The Fertilizer Institute

Sulphur

Sulphur deficiency results in a uniform pale green chlorosis throughout the plant. Veins do not retain a green colour, and in many cases, they may be even paler than the interveinal tissue. In cultivars in which young leaves are normally green (i.e. lacking red pigmentation), the youngest leaves may appear pale earlier or more severely than mature leaves.

A considerable reduction in growth may be suffered without the appearance of any visible symptoms. Clear symptoms are associated with severe stunting, accompanied by reduced leaf size, and reduced activity of axillary buds, resulting in less branching.

Figure 2.42 Sulphur deficiency in peas

Courtesy of: The Fertilizer Institute

Figure 2.43 Sulphur deficiency in canola

Courtesy of: The Fertilizer Institute

Figure 2.44 Sulphur sufficient (left) and sulphur deficient (right) in sunflower

Courtesy of: The Fertilizer Institute

Figure 2.45 Sulphur deficient barley plant, showing pale yellow younger leaves with green older leaves.

Courtesy of: The Fertilizer Institute

Figure 2.46 Yellow chlorotic sulphur deficient leaf (left) compared with normal green leaf (right).

Courtesy of: The Fertilizer Institute

Figure 2.47 Sulphur deficiency in wheat

Figure 2.48 Sulphur source trial with plot showing sulphur deficiency in soybeans

Courtesy of: The Fertilizer Institute

Figure 2.49 Sulphur sufficient (left) and sulphur deficient (right) in flax

Courtesy of: The Fertilizer Institute

Iron

Iron deficiency starts with a yellowing of the leaves between the dark green veins, giving the leaves a spidery look. Over time, the leaves become whitish and start to die back, eventually resulting in stunting and dying back of the entire plant.

Figure 2.50 Iron deficiency in chickpea

Courtesy of: The Fertilizer Institute

Figure 2.51 Iron deficiency in soybean

Table 2.18 Field Risk of Iron Deficiency Chlorosis Based on Carbonate and Soluble Salt Soil Test Levels

Soluble Salts	Carbonate Level (%)		
(mmhos/cm)	0 to 0.25	2.6 to 5	>5.0
0 to 0.25	Low	Low	Moderate
0.26 to 0.50	Low	Moderate	High
0.50 to 1.0	Moderate	High	Very High
>1.0	High	Very high	Extreme

Courtesy of: Manitoba Pulse - Agvise Laboratories

Figure 2.52 Iron deficiency in wheat. Temporary fading of interveinal tissues with prominent green veins

Courtesy of: The Fertilizer Institute

Figure 2.53 Iron deficiency in barley. Deficiency symptoms first appear on younger leaves while older leaves remain normal.

Courtesy of: The Fertilizer Institute

Figure 2.54 Iron deficiency in barley.

Courtesy of: The Fertilizer Institute

Figure 2.55 Iron deficiency in canola

Courtesy of: The Fertilizer Institute

Calcium

Calcium deficiencies are normally caused by nutrient imbalances in the soil profile. Typically, when other positively charged ions such as sodium and potassium are at high levels, they compete with calcium ions in the binding sites on cell walls. Calcium's flow rate through the plant can be affected by transpiration rates, as calcium is absorbed passively in the soil and moves in the xylem as transpiration occurs. When transpiration is slowed, a calcium deficiency may be observed in fruits and new leaves, as well as other areas with low transpiration capacity.

Signs of a deficiency appear initially as a localized necrosis leading to plant stunting, spotted chlorotic areas on leaves, leaf curling and eventually death of the terminal buds and root tips. Generally, areas of newest growth and rapid growth are affected first.

Figure 2.56 Calcium deficiency in soybeans

Courtesy of: The Fertilizer Institute

Note: Notice the chlorotic leaves with cupped margins.

Figure 2.57 Calcium deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.58 Calcium deficiency in canola

Courtesy of: The Fertilizer Institute

Figure 2.59 Calcium deficiency in corn

Courtesy of: The Fertilizer Institute

Calcium deficiency in corn may display the youngest leaves remaining rolled and joined together at their tips. Calcium deficient corn will have tip ends of the leaves glued together causing a ladder-like appearance.

Magnesium

Magnesium is the core of the chlorophyll molecule in plant cells. Shortages will typically occur in very acidic soils, with a pH lower than 5.5, as the element becomes insoluble. Since magnesium is mobile within the plant, the first deficiency symptoms appear on the oldest leaves as interveinal chlorosis. If the deficiency is prolonged, necrosis or red stems may be visible. A magnesium deficiency can enhance the symptoms of a phosphorus deficiency.

Figure 2.60 Magnesium deficiency in corn. Yellow to white interveinal chlorosis.

Note: The purpling colour along the edge of the leaves in the magnesium-deficient corn images.

Courtesy of: The Fertilizer Institute

Figure 2.61 Magnesium deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.62 Magnesium deficiency in soybeans

Courtesy of: The Fertilizer Institute

Manganese

Manganese plays a vital role in splitting water molecules during photosynthesis and aids in chlorophyll synthesis. Due to this role in photosynthesis, the symptoms appear very similar to magnesium deficiency. Manganese is mobile in the plant causing symptoms to appear in younger leaves first which can look similar to iron deficiency. As the pH of the soil increases, the amount of available manganese decreases, as manganese becomes insoluble at higher pHs. Manganese deficiency is most common on poorly drained soils and where organic matter levels are high. Symptoms of manganese deficiency include chlorosis on young leaves followed by old leaves and interveinal chlorosis. Plant leaves may also turn yellow to pale green.

Figure 2.63 Manganese deficiency in soybeans

Courtesy of: The Fertilizer Institute

Figure 2.64 Manganese deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.65 Manganese deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.66 Manganese deficient corn plant. Pale green young leaves with pale yellow interveinal chlorosis.

Courtesy of: The Fertilizer Institute

Boron

Boron deficiencies are closely related to soil pH and are less available in soils with high pH values, such as alkaline soils. The nutrient is most accessible in soils with a pH between 5.0 and 7.5. Boron plays a crucial role in maintaining cell wall structure, protein formation, and improving seed set under stressful conditions. Symptoms of boron deficiency can include dying growing tips, bushy and stunted growth, and in severe cases, it may prevent seed formation .

Figure 2.67 Boron deficiency in canola deficient leaf (left) versus healthy leaf (right)

Courtesy of: The Fertilizer Institute

Figure 2.68 Boron deficiency in canola

Figure 2.69 Boron deficiency in canola

Courtesy of: The Fertilizer Institute

Figure 2.70 Boron deficiency in peas

Courtesy of: The Fertilizer Institute

Figure 2.71 Boron deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.72 Boron deficiency in wheat

Courtesy of: The Fertilizer Institute

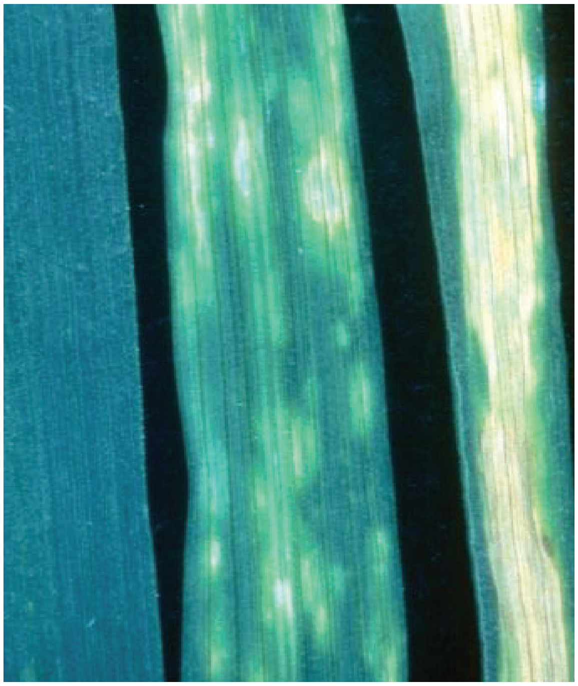
Zinc

Zinc deficiencies are more likely to occur in light or sandy soils with low organic matter and high pH soils. Symptoms will appear as interveinal chlorosis in the new leaves, which can look like banding. Plant growth is stunted, and leaves will appear smaller than normal, with increased severity leaves will eventually die and fall off the plant.

Figure 2.73 Zinc deficiency in soybean

Courtesy of: The Fertilizer Institute

Figure 2.74 Zinc deficiency in wheat



Courtesy of: The Fertilizer Institute

Zinc deficiency in corn may initially display as white to yellow bands which begin at the base of the leaf. The midrib and leaf margins remain green.

Figure 2.75 Zinc deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.76 Zinc deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.77 Zinc deficiency in barley

Courtesy of: The Fertilizer Institute

Note: Initial Symptoms of zinc deficiency in barley may be exhibited by pale, yellow, linear, chlorotic areas.

Figure 2.78 Zinc deficiency in barley. Leaf shows advanced symptoms of grey or brown necrotic lesions.

Courtesy of: The Fertilizer Institute

Copper

Copper deficiencies can occur in high pH (7.5 or greater), high organic matter, poorly drained or light sandy soils. Copper is relatively immobile in plants, leading to symptoms appearing on the new leaves first. A common symptom of copper deficiency is twisting of the leaf tips (pigtailing) which wilt and eventually die. Copper deficiency in wheat may appear as young leaves become pale green to yellow, as well as leaves may be shriveled and/or broken. Wheat heads can become deformed and have poor seed set.

Figure 2.79 Copper deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.80 Copper deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.81 Copper deficiency in wheat: Copper deficient plant showing wilting, rolling, and death of the tips of its youngest leaves.

Courtesy of: The Fertilizer Institute

Figure 2.82 Copper deficiency in barley

Courtesy of: The Fertilizer Institute

Molybdenum

Molybdenum deficiencies typically occur when the soil pH is acidic, or available phosphorus levels are low. Molybdenum deficiency symptoms resemble nitrogen deficiencies due to molybdenum immobility within a plant. Older leaves turn chlorotic, leaf margins can curl, and growth and flower formation are restricted.

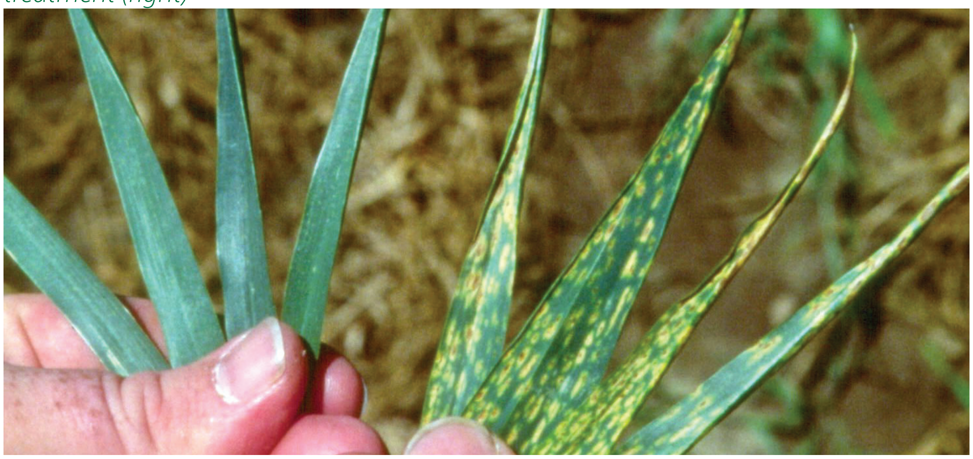
Figure 2.83 Molybdenum deficiency in wheat

Courtesy of: The Fertilizer Institute

Chloride

Chloride deficiencies in plants can be challenging to identify because their symptoms often resemble those of a disease. The first signs usually appear as chlorotic spotting on the young leaves, which may then lead to wilting. Chloride is mobile in soil, and deficiencies tend to manifest more quickly in light, sandy soils that are prone to leaching. Chloride plays several important roles in plants, including facilitating nutrient transportation, aiding in water retention, and contributing to stem strength.

Figure 2.84 Chloride deficiency in wheat showing with Cl treatment (left) vs no Cl treatment (right)



Courtesy of: The Fertilizer Institute

Figure 2.85 Chloride deficiency in wheat

Courtesy of: The Fertilizer Institute

Figure 2.86 Chloride deficiency in canary seed (left) normal and (right) deficient

Courtesy of: Agriculture and Agri-Food Canada (AAFC)

Section 3: Insects and Vertebrate Pests

Bertha Armyworm

Mamestra configurata (Walker)

Description

Adult moths are predominately grey with flecked patches of black, brown, olive or white scales; active mostly at night.

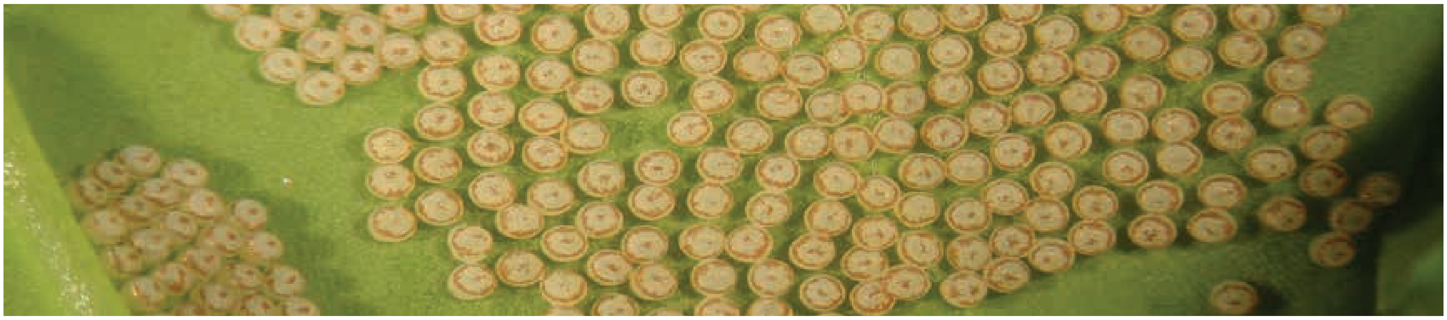
Newly emerged larvae (0.3 mm long) are pale green with pale yellow stripes along each side. Mature larvae (up to four cm long) are a green to brown or velvety black colour with a yellowish-orange stripe down each side.

Figure 3.1 Bertha armyworm

Figure 3.2 Bertha armyworm

Figure 3.3 Bertha armyworm

Figure 3.4 Bertha armyworm egg cluster



Damage

Larvae chew irregular shaped holes in leaves. Feeding can also be on stems or pods, giving a striped look. Larvae will chew into pods and eat seeds.

Scouting

Larvae can be on the upper or underside of leaves and will drop off the plant and/or curl up when disturbed. The larvae can be difficult to see and may be hidden in soil, under leaf litter or curled in leaves. Most damage occurs from the end of July to late August.

Larvae take about six weeks to develop from egg to pupa and can darken with each moult. Adult flight occurs from early June to mid-July.

Economic Threshold

The economic threshold for bertha armyworm varies with the cost of the insecticide, the method of application and the value of the crop. Using current crop value ($/bushel) and application costs ($/acre), Table 3.1 indicates the larval density (number of larvae per square metre) at which an insecticide treatment in canola is warranted. For example, at a crop value of $9/bushel and a spraying cost of $7/acre, the threshold level is 20 larvae per square metre.

If chemical control is warranted, consult with the label to determine what time of day is best to spray.

Overwintering

Bertha armyworm overwinters as pupae in the ground at depths of five to 16 centimetres (two to 6.3 inches).

Figure 3.5 Bertha armyworm pupae

Figure 3.6 Bertha armyworm adult moth

Figure 3.7 Bertha armyworm trap

Table 3.1 Economic thresholds for bertha armyworm on argentine canola, B. napus

Spraying Cost-$/ac	Expected seed value-$/bushel										
	9	10	11	12	13	14	15	16	17	18	19
	# larvae/ metre^2										
7.00	13	12	11	10	9	9	8	8	8	8	8
8.00	15	14	13	11	11	10	9	9	9	9	9
9.00	17	16	14	13	12	11	10	10	10	10	10
10.00	19	17	16	14	13	12	11	11	11	11	11
11.00	21	19	17	16	15	14	13	12	11	11	10
12.00	23	21	19	17	16	15	14	13	12	12	11
13.00	25	22	20	19	17	16	15	14	13	12	12
14.00	27	24	22	20	19	17	16	15	14	13	13
15.00	29	26	23	22	20	19	17	16	15	14	14
16.00	31	28	25	23	21	20	18	17	16	15	14
17.00	33	29	26	25	23	21	20	18	17	16	14
18.00	35	31	28	26	24	22	21	19	18	16	15
19.00	37	33	29	28	25	24	22	20	18	17	16
20.00	39	34	31	29	27	25	23	21	19	18	16
21.00	41	36	32	31	28	26	24	22	20	19	17
22.00	43	38	34	32	30	28	25	23	21	19	18
23.00	45	39	35	34	31	29	26	24	22	20	18
24.00	47	41	37	35	32	30	28	25	23	21	19
25.00	49	43	38	37	34	31	29	26	24	21	19

Modified from Bracken, G. K., and G. E. Bucher. Journal of Economic Entomology. 1977 Dec 1;70(6):701-5
Based on normal feeding activity: an average of 0.058 bushels/larva/acre/day

Cabbage Root Maggot

Delia radicum (L.)

Description

Adult flies are light grey and are approximately 4 to 6 mm long. At rest, the wings overlap. Mature larvae are whitish and are approximately 8 mm long. Puparia are reddish-brown, cigar-shaped, and are found about 5 - 20 cm below the soil surface.

Damage

Preferred hosts are all in the Brassicaceae family and include canola, camelina, and brassica vegetables. Females are attracted to the visual and olfactory cues from host plants and will use these and the tactile and chemical cues from leaf surfaces to evaluate potential hosts. Eggs are laid at the soil-stem interface. Spring generation females prefer canola in the four to six leaf stage. Damage is caused by the larval stage and is most severe in cool and damp soil conditions. There are three larval instars that feed on roots. Young maggots feed on root hairs. As the maggots moult and grow, they consume larger roots and burrow into the tap root when mature. This damage causes wilting and yellowing in lower leaves and may also promote disease. Very heavy infestations can delay blooming and cause severe lodging and yield loss. Infested roots are often darker than normal.

There are typically two generations per year on the Prairies but a third is possible under very warm conditions in canola with adults laying eggs from late spring into October. Maggots will feed on roots from late rosette stage until late fall. A complex of five Delia species occurs in prairie canola including *D. radicum, D. floralis* (Fallén), *D. planipalpis. D. platura* (Meigen), and *D. florilega* (Zett.)

Figure 3.8 Cabbage root maggot pupae

Figure 3.9 Cabbage root maggot larvae

Scouting

In mid-May, the adult flies emerge to mate and the females lay about 200 elongate white eggs over a five to six week period.

Throughout the season, pull plants and check the roots for any signs of damage caused by root maggot larvae. Note any channels on the taproot, or tunnels throughout the taproot, and look for the presence of larvae. Yellowing of bottom leaves may also be noticed.

Canola on canola rotations will have increased levels of infestation damage and yield loss may be more significant.

Management options include crop rotation. At least a one-year break between canola crops is recommended. Increasing seeding rates can decrease damage.

There are no chemical management options registered in Canada.

Economic Threshold

None have been established.

Overwintering

Pupae overwinter in the soil near host crops.

Cabbage Seedpod Weevil

Ceutorhynchus obstrictis (Marsham)

Description

Adult cabbage seedpod weevils are approximately 3 to 4 mm long and are ash-grey. They have a prominent curved snout that is characteristic of long-snouted weevils. It takes approximately eight weeks for cabbage seedpod weevils to develop from egg to adult. Pupation occurs in the soil in an earthen cell. Larvae are small, white, and grub-like and hatch from eggs deposited in holes that the female has chewed in pods. They feed on developing seeds.

Several weed species including flixweed and stinkweed can be alternate hosts for cabbage seedpod weevil.

Damage

Adult weevils feed on developing flower buds. An individual egg is deposited through a hole chewed by the female in the wall of a developing pod. Larvae feed within pods and exit by chewing a small circular hole in the pod walls. Both the egg laying hole made by the female and the exit hole caused by the larvae can contribute to shatter and allow disease to enter.

Figure 3.10 Cabbage seedpod weevil adult

Note: Yellow mustard is resistant to cabbage seedpod weevil, however, economic damage can occur in brown and oriental mustard and camelina.

Scouting

When disturbed, adult cabbage seedpod weevil will drop to the ground and play dead. Monitoring for adults can be done by sweeping fields at bud to flowering stage.

Figure 3.11 Cabbage seedpod weevil larva exit

Economic Threshold

Two to four adults per sweep. Greater tolerance should be used when the crop is not under stress.

Insecticide application targets adults when crops are in the 10 to 20 per cent flower stage (when 70 per cent of plants have at least three to 10 open flowers) to avoid eggs being laid in newly formed pods.

If an insecticide application is required, spray in the morning or evening when temperatures are between 15 C to 24 C for best results and to protect pollinators. Avoid spraying under a strong temperature inversion or when temperatures exceed 25 C. See Canola and Mustard Development and Stages in Section 1 for guidance on staging flowering canola.

Overwintering

Adult cabbage seedpod weevils overwinter in the soil beneath leaf litter in tree shelterbelts, roadside ditches and woodlots.

Figure 3.12 Cabbage seedpod weevil damage to canola pod

Canola Flower Midge

Contarinia brassicola (Sinclair)

Description

Adult canola flower midge are small, delicate flies (1.5-2.0 mm), that superficially resemble swede midge or tiny mosquitoes. Adult canola flower midge wings often have distinct dark splotches created by fine hairs. Larvae are initially white and turn yellow as they mature and will wriggle if disturbed.

Damage

Most damage is associated with induced flower galls on canola, however, there have been cases of larvae found feeding on seeds inside of pods.

Scouting

Scout along the field edge for galled, bottle-shaped flower buds containing larvae after crops come into flower.

Economic Threshold

Although reports occur, damage is very rarely economic.

Similar species

See swede midge under species of interest.

Overwintering

Overwinters in cocoons in the soil. Adults emerge from the soil in mid-June through to August.

Figure 3.13 Canola flower midge fused canola flowers

Figure 3.14 Canola flower midge larvae

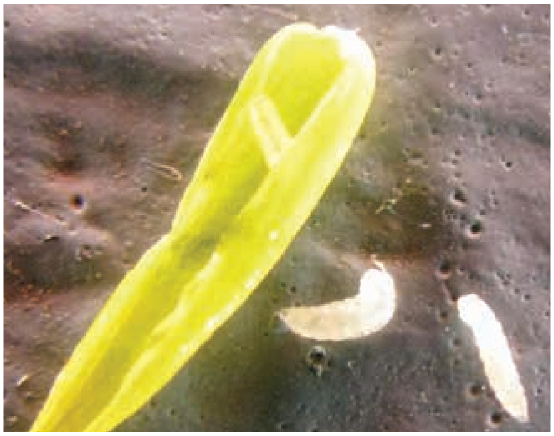


Figure 3.15 Canola flower midge larvae inside of fused flowers

Figure 3.16 Canola flower midge larvae inside of fused flowers

Diamondback Moth

Plutella xylostella (L.)

Description

Adult moths are approximately 8 to 9 mm long with a 12-15 mm wingspan. At rest, the moth folds its wings to cover the abdomen in a tent-like manner. Wings flare upward at the tips and wing tips are fringed with long hairs. Larvae are pale yellowish to green caterpillars covered in fine, erect hairs. At maturity, larvae are spindle or cigar-shaped and about 12 mm long. Larvae pupate in delicate, white open mesh cocoons attached to leaves, stems or pods that remain intact and on the plant after the larvae exit.

Figure 3.17 Diamondback moth mesh cocoon

Figure 3.18 Diamondback moth larvae

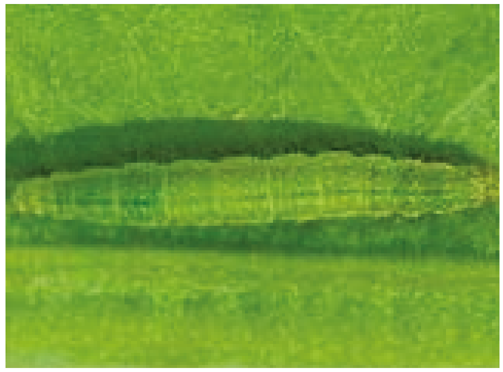


Figure 3.19 Adult diamondback moth

Damage

Crop damage is caused by the larval stage. Larvae prefer to feed on leaves but will also feed on any green tissue on host plants. Damaged leaves will have small irregular holes. Larvae can eat an entire leaf, leaving only the veins. Newly hatched larvae tunnel leaves. Larger larvae feed on buds, flowers and young pods.

Scouting

Look for crop damage in late-June to early-August on leaves, stems, flowers and pods. Crop damage is usually first evident on ridges and knolls in fields. When disturbed, larvae will wriggle violently and may drop from the plant attached with a silken thread. They will eventually return to the leaf and continue to feed.

Economic Threshold

- 100 -150 larvae/m^2 in immature and flowering canola
- 200-300 larvae/m^2 in podded canola

Overwintering

Very few, if any, survive the long, cold Canadian winters. They are blown into Manitoba, Saskatchewan and Alberta on high altitude winds as early as April.

Figure 3.20 Diamondback moth larvae hanging from plant with silken thread

Figure 3.21 Diamondback monitoring trap

Flea Beetles

Phyllotreta cruciferae (Goeze)-Crucifer flea beetle
Phyllotreta striolata (F.)-Striped flea beetle

Description

Adult crucifer flea beetles are small (2 to 3 mm), black beetles with a metallic sheen. Striped flea beetles are similar in size and are black with distinctive yellow stripes down their backs.

Larvae are grub-like with off-white bodies and a brown head. Larvae are present in mid-June to late July and feed on root hairs and taproots of seedlings. The adults that are seen in late summer overwinter and emerge in the spring to damage crops and lay eggs.

Figure 3.22 Striped flea beetle on canola leaves

Figure 3.23 Late season new adults

Damage

Adult beetles emerge from leaf litter and shelterbelts and begin feeding on whatever Brassicaceae plants are available. These can sustain adults until the emergence of canola seedlings. Striped flea beetles emerge about two weeks before crucifer flea beetles and can be present in large numbers as early as mid to late-April. Adults feed on cotyledons, leaves, petioles, and stems in the spring and can cause economic damage. Second generation flea beetles will feed on pods of crucifer plants in late summer and can cause yield damage in rare cases, but no economic threshold has been established for this generation.

Scouting

Scout fields in early spring for damage to newly emerging seedlings. Warm, sunny, dry weather increases the intensity of feeding, particularly on days above 14 C. Continue scouting for 14 days after emergence or until plants reach the three to four leaf stage when plants can generally outgrow feeding damage. Meristem or stem feeding is most severe on new seedlings.

Economic Threshold

Consider foliar treatments at 25 per cent cotyledon leaf and first true leaf damage if flea beetles are present and actively feeding.

Flea beetles overwinter (as adults) near the surface of the leaf litter, grass and debris beneath hedges, shelterbelts, poplar groves and in association with canola stubble and volunteer cruciferous plants belonging to the family Brassicaceae or (previously referred to as) Cruciferae.

Figure 3.24 Flea beetle

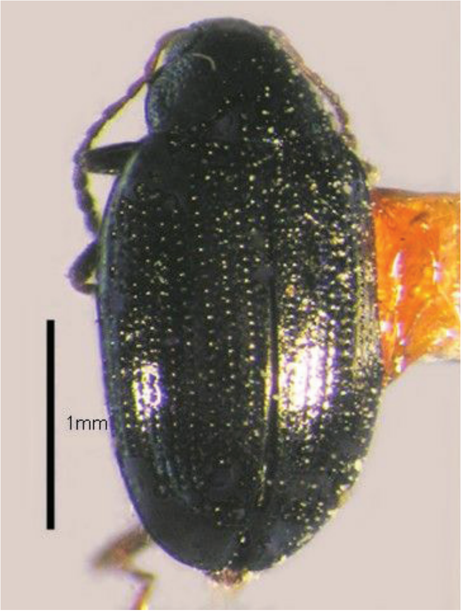


Figure 3.25 Flea beetle

Courtesy of: University of Idaho

Figure 3.26 Crucifer flea beetle

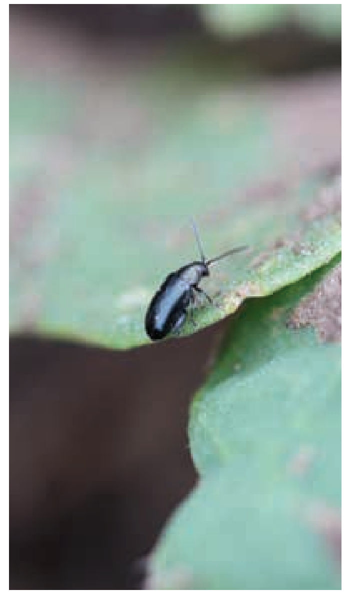
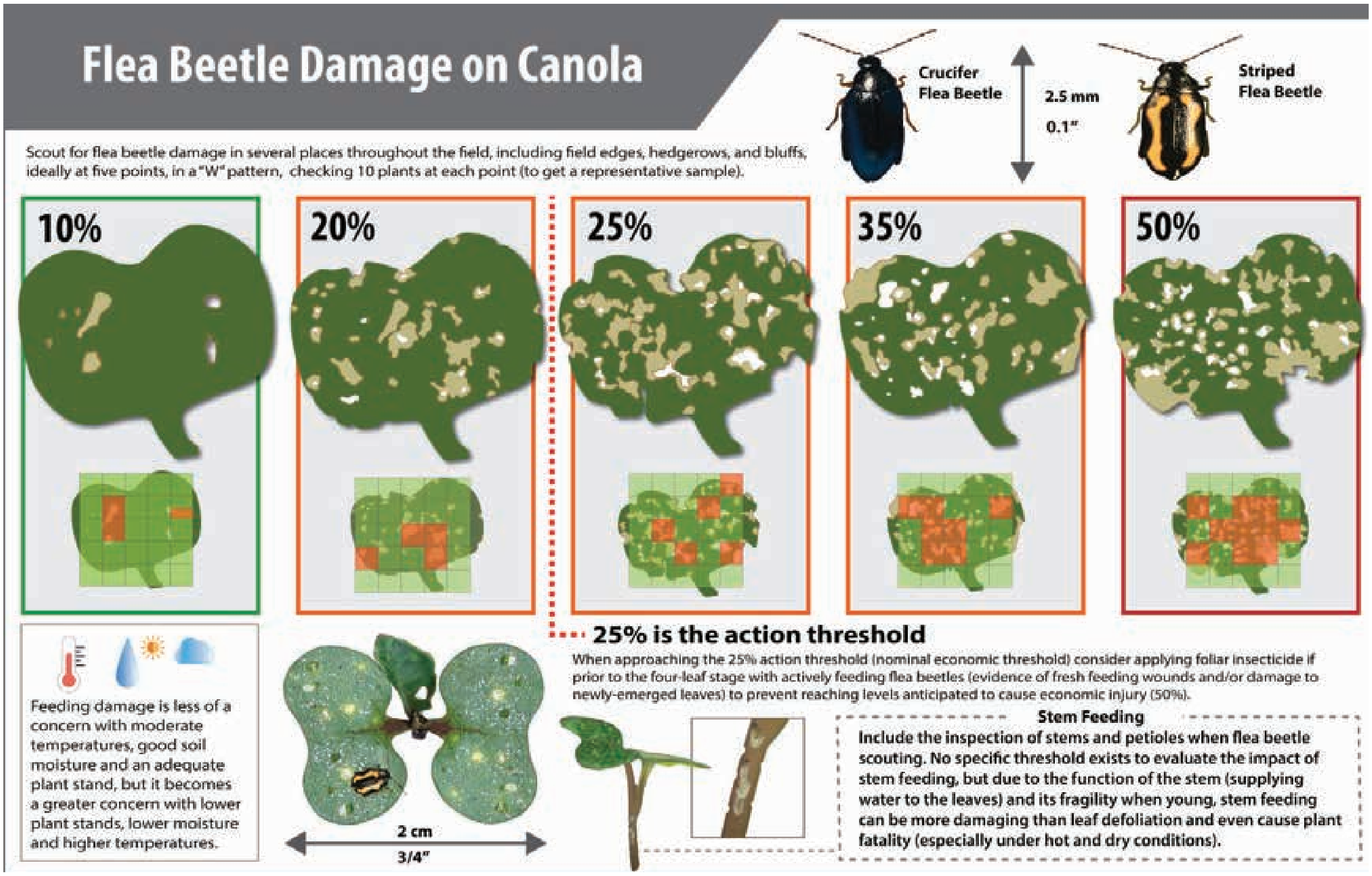


Figure 3.27 Spring and fall populations of flea beetle

Figure 3.28 Striped flea beetle

Figure 3.29 Cotyledon damage from flea beetle feeding



Courtesy of: Canola Council of Canada

Three Spotted Flea Beetle

Disonycha triangularis

Description

The three spotted flea beetle may be found in fields of canola and mustard and may cause questions of concern due to its similarity to other flea beetle pests in canola. However, the three spotted flea beetle is less common and almost never numerous enough in population to be damaging to crops. It's also a lot larger (6mm) than the typical pest flea beetle species (2mm).

Figure 3.30 Three spotted flea beetle

Red Turnip Beetle

Entomoscelis americana Brown

Description

Adults are approximately seven to 10 mm long with a red body and black patches on their head and thorax. Red turnip beetles also have three distinct black stripes running down their back. At maturity, the larvae are about 10-15 mm long, with smoky black colouring on the top, and brownish underneath. They are long, hump-backed, and slow-moving. Larval development is usually completed by the end of May.

Damage

Adult beetles feed on flowers, seed pods, petioles, and stems of canola, rapeseed, mustard, and weeds from the Brassicaceae family. Larvae feed on volunteer host plants in the spring. When feeding, adults move in from the field margins in a band.

Scouting

In late April to mid-June, scout previously infested fields for larvae feeding on volunteer crop and weed hosts. Monitor the margins of nearby host crops after crop emergence for presence of invading adults.

Economic Threshold

No economic threshold has been developed for red turnip beetle.

Overwintering

It overwinters in the soil as reddish-brown oval eggs.

Figure 3.31 Red turnip beetle

Thrips

Frankliniella occidentalis-Western flower thrips
Thrips tabaci-Onion thrips
Thrips vulgatisimus-no common name

Description

Thrips are small, thin insects with rasping-sucking mouthparts. Their life stages are egg, two larval stages, a prepupal, a pupal and an adult stage. Life cycle completion from egg to adult takes approximately 19-20 days with temperatures at 20 C but only 13-14 days at 25 C.

Damage

Both the adult and the nymphs feed on the surface of canola buds and on flowers by rasping the surface and sucking up plant fluids. This feeding creates curled pods and pod abortion.

Scouting

Damage from thrips can be observed when canola is podding.

Economic Threshold

Research done by AAFC indicates there are no significant yield differences between treated and untreated plots at any thrips density.

Overwintering

Adult thrips overwinter in plant debris.

Figure 3.32 Thrips damage in canola causes the pod to curl

Figure 3.33 Female thrips

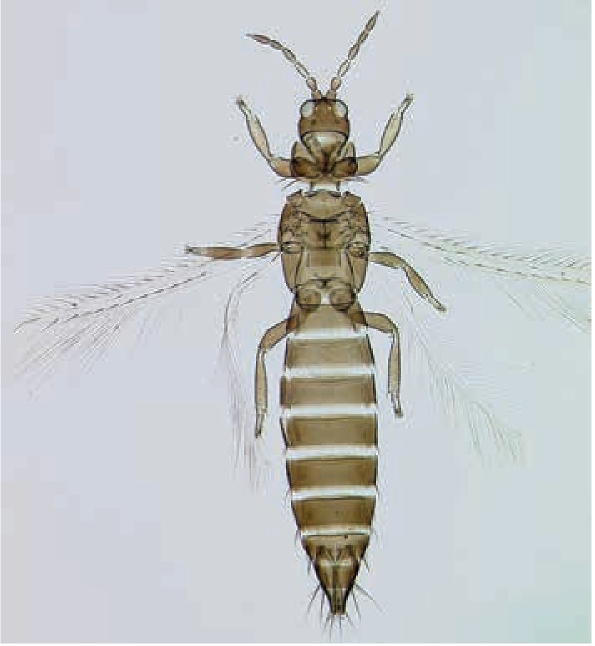


Figure 3.34 Thrips damage in canola

Figure 3.35 Thrips damage in canola

White Cabbage Moth aka Imported Cabbage Worm

Pieris rapae

Description

White cabbage moths feed on many brassica plants including canola, mustard, and vegetables. Adults have white wings with black at the tips and have a wingspan of 4.5 to 6.5 cm. Females have two black dots in the middle of each wing whereas males only have one dot on each wing. Adults are most active during the day. Mature larvae are 2.5 to 3 cm long with a fuzzy-textured green body with a broken yellow line along each side.

Damage

Adults feed on nectar in the flowers of host plants while larvae primarily feed on the leaves and pods of host plants. Despite crops such as canola and mustard being hosts for white cabbage moth, they do not cause economic losses.

Scouting

No scouting techniques have been developed for this pest.

Overwintering

White cabbage moth overwinters on host plants in the pupal stage. During mid-spring, adults will emerge and lay eggs on the underside of host leaves. In total, it takes between three to six weeks for eggs to develop into adults, and the adults live for approximately three weeks. Since white cabbage moth has a short lifecycle, it is possible to see two or three generations in a growing season.

Figure 3.36 Female white cabbage moth

Figure 3.37 Male checkered white butterfly. Often mistaken for the white cabbage moth

Figure 3.38 White cabbage moth larvae

Barley Thrips

Limothrips denticornis (Haliday)

Description

Adults are very narrow bodied and 1.1-1.8 mm long. Females have narrow forewings that are fringed with long hairs while males are wingless. Larvae are 0.25-1.8 mm in length with white to pale yellowish-green bodies that are wingless. They have red eye spots.

Damage

Adults and nymphs both cause damage to cereal plants. They have piercing, sucking mouthparts that are used to puncture and suck out plant cell contents. As a result, severe damage can be seen as white heads and stems along with heads that are twisted and gooseneck shaped. If heavy damage occurs on the flag leaf, kernels will not fill properly and seed weight will be reduced as a result.

Scouting

Start scouting when the flag leaf is first visible and continue until total head emergence from the boot occurs. Unroll the leaf sheath away from the stem on the top two leaf sheaths for at least nine plants.

Economic Threshold

Threshold (thrips/stem) = (cost of control per acre/ expected $ value per bushel)/0.4

Sample at least 50 stems from different parts of the field. One adult thrips per stem can cause a loss of 0.4 bushels per acre. This translates to an average economic threshold of seven to eight thrips per stem prior to head emergence but greater precision can be achieved by using the formula. Lower numbers than this do not warrant control but may need to be monitored to assess possible population growth. Only apply control prior to the completion of heading.

Overwintering

Females overwinter in bromegrass or bluegrass sod along shelterbelts.

Figure 3.39 Barley thrips adult. Unroll the stem at the leaf sheath when looking for adults

Figure 3.40 Thrips feeding on canaryseed leave a tell- tale white head as a symptom.

Cereal Leaf Beetle

Oulema melanopus

Description

Eggs are laid on the upper surfaces of the leaves. New eggs are laid in clusters of two to three that are yellow in colour, while older eggs will be a darker orange measuring from 0.4 mm - 0.9 mm.

Larvae are 4 - 5 mm in length with a humped back yellow body covered in slimy fecal material.

Adults are 6 - 8 mm long with dark metallic blue wings and head with a red thorax.

Damage

Cereal leaf beetles are a pest that commonly feed on barley, wheat, oats and other cereal crops. The fourth larval instar is the most damaging stage of the cereal leaf beetle, although adults will cause damage as well. Larval feeding is where 70 per cent of the damage occurs. The highest yield losses occur from feeding on the flag leaf.

Scouting

Scout just before the boot stage and look for eggs or larvae on the upper surface of the leaves.

Economic Threshold

Control may be warranted if there are three or more eggs and larvae per plant at the pre-flag stage. However, one or more larva per flag leaf at the boot stage may warrant control.

Figure 3.41 Cereal leaf beetle larvae

Figure 3.42 Cereal leaf beetle

Figure 3.43 Cereal leaf beetle damage

Figure 3.44 Cereal leaf beetle with parasitoid Tetrastichus julis inside

Hessian Fly

Mayetiola destructor

Description

The hessian fly is a small fly in the gall midge family. The female is a small fly that appears dark with a striped pattern on its abdomen. These females will then lay reddish eggs on the leaves of wheat, barley, rye and wild grasses but will not attack oats or rye grass. The larvae which appear red after a few days after hatching will eventually turn white and will feed on the grassy plant for up to 30 days. The shape and shininess of the pupa makes it look like a flax seed.

Damage

The flies have two generations. The first generation is in September which can damage young winter wheat. Plants attacked in September will have a darker colour than normal with broad blade leaves. Young plants that host larvae can die over winter. Plants attacked in the spring will have shortened or weakened stems causing them to break.

Figure 3.45 Hessian fly

Courtesy of: University of Kentucky

Scouting

Collect about 50 stems within a field avoiding the headlands. Examine the base of the leaves in the crown or in the sheath. Pupae can typically be found in these areas. Plants can either be dead or stunted, have fewer leaves and stems can be tipped over or broken off. Heavily infested areas can be lodged.

Economic Threshold

Control is based on prevention and crop rotation, therefore, there is no economic threshold.

Overwintering

Hessian fly overwinter between leaf sheaths and stems, or can be knocked into crop residue.

Figure 3.46 Hessian fly pupa

Courtesy of: University of Kentucky

Figure 3.47 Hessian fly puparia and larvae

Courtesy of: University of Kentucky

Wheat Midge

Sitodiplosis mosellana (Gehin)

Description

Adults are small, orange and are about 2 to 3 mm. These adult flies resemble mosquitoes and typically emerge from the soil between late June and July. They lay their eggs on developing wheat heads. The larvae, which are initially small and creamy white when young, grow to 1-2 mm in length. As they mature, the larvae darken to an orange colour.

Damage

Damage is most common in spring wheat. Although barley, couch grass, intermediate wheat grass and rye are also attacked, damage is rarely significant in these plants. Spring wheat is the primary host for newly hatched wheat midge. Larvae crawl into wheat glumes and feed on the developing wheat kernel.

Scouting

Scout for adults on a calm evening when temperatures are above 15 C, when females become active at the top of the canopy, laying eggs on newly emerged wheat heads. Wheat is most susceptible to damage when egg laying occurs during heading and diminishes through heading to anthesis, however, tillering will increase this window.

Scout wheat by walking 10 metres in from the field edge and crouch down so you are at eye level with the wheat heads. Patiently wait and count how many wheat midge are active on 10 wheat heads, gathering an average midge per head value. Repeat count at a minimum of five locations in the field.

Economic Threshold

An insecticide application is recommended when there is at least one adult midge for every four or five wheat heads. At this level of infestation, wheat yields can be reduced by approximately 15 per cent. Lower densities can effect quality, so a normal threshold for quality is set at one midge per eight to ten heads.

Grade Consideration

The Canadian Grain Commission's changes to grading tolerances have prompted re-evaluation of the economic threshold for wheat midge to maintain optimum grades. In areas where growing conditions are favourable to the production of No. 1 grade wheat, chemical control may be required when midge populations reach one adult midge for every eight to 10 wheat heads during the susceptible stage.

Overwintering

Larvae overwinter in soil at depths of 5-10 cm.

Figure 3.48 Wheat midge adult

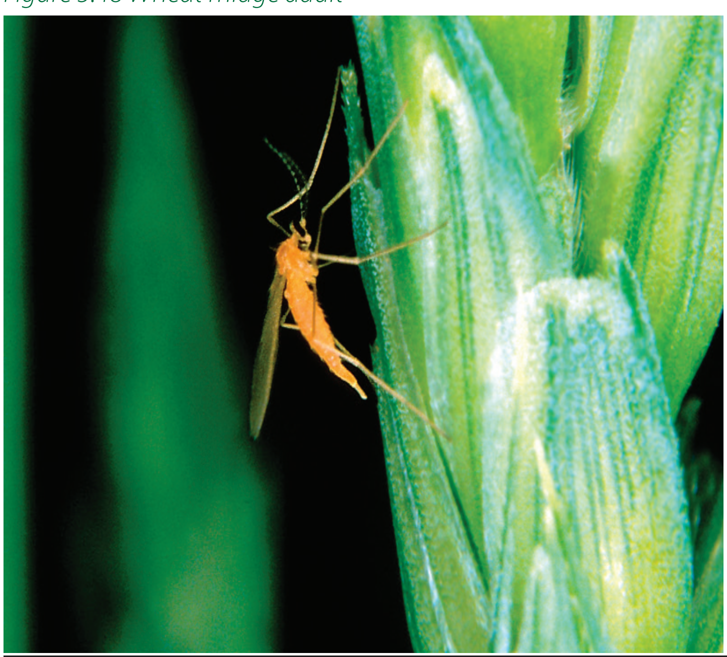


Figure 3.49 Wheat midge larva

Figure 3.50 Normal CWRS wheat (left) and damaged wheat (right)

Figure 3.51 Wheat midge

Midge Busters

Midge Busters is an in-season monitoring network developed by Dr. Tyler Wist, field crop entomologist, AAFC and SeCan. It involves volunteers across the Prairies (SeCan members and staff as well as independent agronomists) using pheromone traps to count and report midge activity in real time during the growing season. Participants enter their trap catches in an online platform so everyone can immediately see counts from other areas. Midge enthusiasts can follow along on X under the #midgebuster hashtag. If you are interested in participating in the #MidgeBusters Program, you can email tyler.wist@agr.gc.ca.

Wheat Stem Maggot

Meromyza americana

Description

Mature larvae are roughly 6-7 mm (¼ in.) in length, and light green to cream coloured. They look like a fly maggot and are usually found inside the stem. The larvae pupate in the spring and the adults emerge in June. After mating, the female flies lay eggs near the sheath of the flag leaf, just one per stem, over a two to three week period. These eggs hatch out in roughly five days into the maggots/larvae. Larval development is complete in 18-21 days and can have two generations per summer.

Damage

The larvae burrow into and consume the interior of the stem, killing the upper part of the stem and the head. In the fall or spring when young tillers are attacked, they usually die. The affected plants show the "white head" or "silver top" condition, typically produced by stem-boring insects. Symptoms present themselves in mid- to late June.

Scouting

The damage is distinctive - white heads without kernels on a plant that is still green. Typically, only one to five per cent of the heads are affected and they are usually scattered randomly throughout the field. If you tug on the head, it will pull out easily. Normally there are signs of insect damage on the stem above the top node.

Economic Threshold

No thresholds have been developed for this pest. Crop rotation can help prevent build-up of populations. Delaying planting may also reduce the impact of this insect.

Overwintering

In cereal plants or grasses, wheat stem maggot larvae overwinter in the lower parts of the stems.

Figure 3.52 White heads in any cereal crop are a symptom of a possible wheat stem maggot damage

Figure 3.53 Wheat stem maggot damage

Wheat Stem Sawfly

Cephus cinctus (Norton)

Figure 3.54 Adult wheat stem sawfly

Description

Adults are 8-13 mm long with a shiny body and yellow legs. At rest, or when on a stem, they point their head downwards. Females have a distinct ovipositor (egg-laying appendage) extending from their abdomen. Mature larvae are 13 mm long and are slender, whitish and grub-like with a brown head. They overwinter in the base of wheat stems in infested fields.

Damage

Crop damage is caused only by the larval stage. In June, adults emerge from infested plants, with males emerging earlier than females. Females then fly to nearby wheat fields to lay up to 50 eggs on plant stems. Usually, only one egg is laid per stem. The adults only live about 10 days and do not feed.

Larvae hatch after five to eight days and feed on the pith of host plant stems. As plants mature, the larvae move to the bottom of the stem to overwinter. They also carve a "V" notch in the stem wall just above ground level making the plants susceptible to lodging. Field damage is often greater in field margins. There is only one generation per year but there is evidence that very high springtime temperatures and dry conditions may induce the larvae back into a resting stage and the generation may take two years to complete.

Scouting

Larvae feed primarily on spring and durum wheat; however, winter wheat, rye, grain corn, barley and some native grasses can support development. Oat crops are unsuitable hosts.

Use a sweep net to sample for adult sawflies in late June-early July. Count the number of sawflies per 10 sweeps but make sure to carefully examine the adults to determine sex as the females can be easily distinguished by the presence of an ovipositor. An average of two females per 10 sweeps generates about 12 per cent cut stems, while four females per 10 sweeps generates about 23 per cent cut stems.

As plant stages prior to stem elongation are not attractive for the sawfly to lay eggs, scouting can begin after this stage. Stems that develop a reddish-brown band below either the second or third node can indicate the presence of sawfly larvae.

While the crop is still green, infested stems may also appear with regions of mottled discolouration. Splitting the stems lengthwise can determine the presence of larvae and any feeding on the stem. This can help provide insights into field damage prior to crop maturity. Scouting closer to harvest can also help determine swath timing as well as the need for management practices next year.

Economic Threshold

If 10 to 15 per cent of the crop in the previous year was cut by sawfly, control may be warranted. However, there are no chemical control products that have been proven effective. Instead, cultural control methods will help reduce populations. These include late seeding, not seeding successive wheat or other host crops, rotating with solid- stemmed varieties, swathing earlier to avoid losses, seeding at rates no more than 300 seeds/m^2, applying 30 to 60 kg/ha (27 to 54 lb./ac) of N and cutting stubble to at least 15 cm during harvest. Shallow tillage in the fall can increase larval mortality rates but only when there is little to no risk of soil erosion.

Overwintering

Wheat stem sawfly overwinter at or below the soil surface. The larvae plug the stem with frass and plant material and produce a long, thin, brown cocoon below the cut stem. Pupae will not be formed until the following May.

Figure 3.55 Normal wheat (left) damaged wheat from wheat stem sawfly (right)

Figure 3.56 Wheat stem sawfly larvae frass

Pea Aphid

Acyrthosiphon pisum (Harris)

Description

Common pea aphid host crops include field peas, lentils, alfalfa and chickpeas.

Adult pea aphids are 3 to 4 mm long with a soft, pear-shaped body. They have long, slim legs and range in colour from light to dark green. The antennae of the pea aphid have narrow dark bands at the tip of each segment. Mature nymphs resemble the adults but are smaller in size. Aphid nymphs can be distinguished from lygus nymphs by the presence of cornicles, which are a pair of conspicuous tubes extending from the top of the aphid's abdomen, used to release an alarm pheromone. Pea aphids can produce seven to 15 generations per year. A single female can produce 50-150 young, contributing to rapid population growth.

Figure 3.57 Pea aphids can reproduce asexually and are clones of the mother

Damage

Pea aphids cause damage to their host plants by sucking plant sap. They feed on the growing points of plants, consuming large amounts of fluid and draining nutrients. Both adult and nymph stages of the pea aphid feed on leaves, petioles, stems, flowers, and young pods. Feeding during the flowering and early pod stages results in yield loss due to reduced seed formation and seed size.

Scouting

Scout when 50 to 75 per cent of the pea plants are in flower. Assessments can be made from five 180 degree sweeps in five locations or at least five, eight-inch (20 cm) plant tips along four or more well-spaced (50m/150ft) stops in the field.

If you suspect pea aphid populations in your area are showing signs of insecticide resistance, please get in touch with your nearest Crops Extension Specialist or Dr. James Tansey at 1-306-787-4669 or james.tansey@gov.sk.ca.

Economic Threshold

Two to three aphids per eight-inch (20 cm) plant tip or nine to 12 aphids per sweep.

Overwintering

Adult pea aphids are primarily migratory and fly or are blown in from established populations in the United States.

Figure 3.58 Pea aphid in peas

Figure 3.59 Pea aphids on lentil leaflet

Pea Leafminer

Liriomyza huidobrensis

Description

Field pea and faba bean crops are common hosts for pea leafminer. Adult pea leafminers are 2 to 3 mm long with a shiny yellow and black body. Adults can fly to host plants and lay their eggs into leaves. The larvae are pale yellow and feed by mining the inside of the host leaves. When the larvae are mature, they cut a hole in the leaf and drop to the ground where they pupate. Leafminers are most active between 21 C and 32 C.

Damage

Leafminers are almost never economically important. Larvae feed on the inside of the leaves and create colourless tunnels in the leaf which resemble a mine. Feeding damage typically occurs on the bottom stipules or on the older leaves of the plant, which does not cause yield loss. In severe cases, the mines in the leaves created by larvae can hinder photosynthesis in the plant.

Scouting

Since leafminers tend to feed on older leaves, look for symptoms on the two oldest leaves of the plant. It is important to inspect multiple plants as not all plants will have damage.

Economic Threshold

No economic threshold.

Overwintering

Pea leafminer overwinter as pupate in the soil.

Figure 3.60 Leaf miner on peas

Figure 3.61 Leaf miner on peas

Figure 3.62 Leaf miner damage on peas

Courtesy of: Sask Pulse Growers

Pea Leaf Weevil

Sitona lineatus (L)

Description

Adults are 5 mm long and are grey with three alternating light and dark stripes on their back or underside. Pea leaf weevils have a relatively short, broad snout, characteristic of the subfamily. Larvae are 3.5-5.5 mm long, "C" shaped, and pale white with dark brown heads.

Damage

Adults consume foliage from the leaf margins leaving characteristic notches. Larvae feed under the soil on the nitrogen fixing nodules of peas and faba bean.

Scouting

When scouting crops in the seedling stage, look for characteristic feeding notches on the leaves.

Economic Threshold

30 per cent of seedlings with notching on the clam leaf during the second to fifth node stage.

Overwintering

The adults overwinter in alfalfa or other perennial legumes.

Figure 3.63 Pea leaf weevil adult with eggs

Figure 3.64 Pea leaf weevil damage in peas

Figure 3.65 Pea leaf weevil on mature pea plant

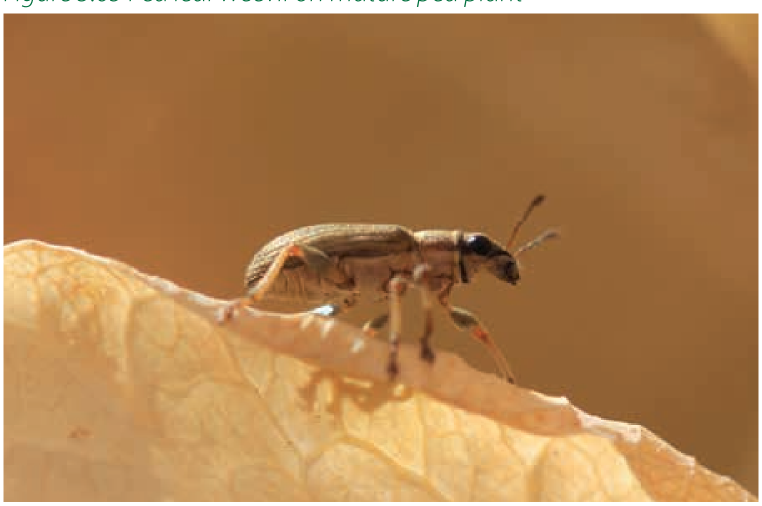


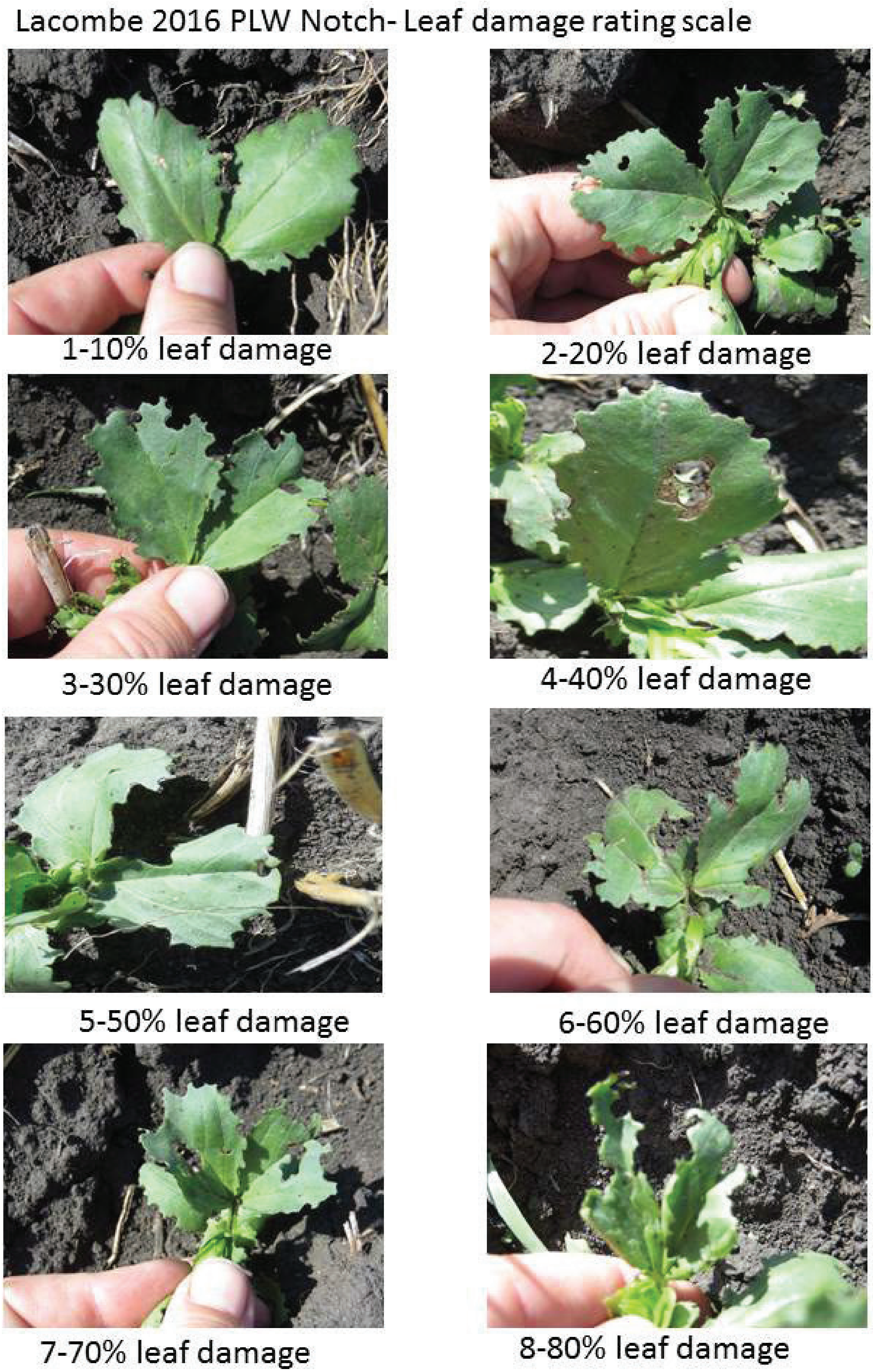
Figure 3.66 Pee leaf weevil damage on faba

Courtesy of: Henri Goulet, AAFC

Figure 3.67 Pee leaf weevil larvae on nodule

Courtesy of: Carolyne Herle

Figure 3.68 Pea leaf weevil damage rating scale for faba beans



Alfalfa Weevil

Hypera postica (Gyll.)

Description

Adult weevils are 4 to 5 mm long and are silvery brown with a darker brown stripe down the centre of the upper side. Mature larvae are about 8 to 9 mm long, bright green with a black head, and have a distinct white stripe down the middle of the upper side.

Damage

Both adults and larvae feed primarily on alfalfa. In late spring and early summer larvae feed on growing tips. Growth of the plants can be stunted. Larvae remove leaf surface tissue causing a silver appearance to heavily infested crops.

Scouting

Look for larvae or feeding damage to plant leaves. Peak feeding of larvae is mid-June to mid-July. Monitor fields with a sweep net or bucket. Fields that are being monitored should be walked in a 'w' shaped pattern to efficiently and thoroughly check for the pest. Collect 30 stems while walking the field and place them into a white pail. Beat the stems against the side of the pail to dislodge the larvae.

Economic Threshold

The following thresholds have been established for alfalfa produced for hay and alfalfa seed production. For alfalfa used as hay, the height of the crop is taken into consideration. If the crop is less than 30 cm in height, one larva per stem is the threshold. For crops less than 40 cm in height, the threshold is two larvae per stem. For any height, the threshold is three larvae per stem. For alfalfa seed production, the threshold is 20 to 30 larvae per seed or 35 to 50 per cent leaf tips showing damage.

Overwintering

Adult weevils overwinter under plant debris and soil, in and around alfalfa fields.

Figure 3.69 Alfalfa weevil adults and larvae

Figure 3.70 Alfalfa weevil eggs

Courtesy of: AAFC

Figure 3.71 Alfalfa weevil monitoring trap

Figure 3.72 Alfalfa weevil adult

Figure 3.73 Alfalfa field heavily damaged by weevil larvae feeding

Alfalfa Plant Bug

Adelphocoris lineolatus

Figure 3.74 Alfalfa plant bug

Description

Adult plant bugs, measuring 7 to 9 mm long and 2.5-3.0 mm wide, are green to yellowish-green with green legs and black spotting on the legs. Mature nymphs resemble adults but are smaller and initially brownish in colour. As they mature, their bodies turn a bright green with small wing pads. The segment on the antenna closest to the head is enlarged, club-like, and black.

Damage

Adults and nymphs are only a problem in seed alfalfa crops. They feed on the flower buds by piercing the leaf tissue and injecting a toxin that causes buds to turn greyish-white, shrivel and die. Crops under heavy pressure show reduced blossoms.

Scouting

Monitor seed alfalfa fields with a sweep net at the beginning of the bud stage until after the bloom stage. Identify the average number of adults and nymphs per sweep.

Economic Threshold

For alfalfa seed crop, the following thresholds are established based on the growth stages. During the pre-bud stage, the threshold is 15 nymphs per sweep. In the bud and bloom stages, the threshold is two to three nymphs and/or adults per sweep. After bloom, the threshold increases to four nymphs or five adults per sweep.

Overwintering

Alfalfa plant bugs overwinter as eggs in the stems of alfalfa. New adults readily disperse to neighboring alfalfa crops that can be kilometres away. Typically there is only one generation per year but under earlier and hot summers a smaller second generation can appear.

Sweet Clover Weevil

*Sitona cylindricollis (*Fahraeus)

Figure 3.75 Sweet clover weevil

Description

Larvae are grub like, white and 5 - 6 mm in size. Adults are 4 - 5 mm in size, dark grey to brown and with the traditional weevil snout.

Damage

Larvae will feed on roots, but major damage can be done by adult weevils feeding on leaves. First year sweet clover plants are extremely vulnerable especially in dry years when plants are stressed due to lack of moisture. Adult weevils may also feed on stems and developing seeds. Studies conducted in Ontario show sweet clover weevil may be of importance in spreading sweet clover root rot disease *Phytophthora cactorum*.

Scouting

While sweet clover is their preferred crop, sweet clover weevils will also be found feeding on other legumes, including alfalfa and cicer milkvetch. Larvae generally start to show up around the first of June but only have one generation per year. Pupation occurs in July and August with new adults showing up around the first part of August.

Economic Thresholds

For a first-year stand of sweet clover, one adult weevil/three seedlings. In a dry year, the threshold should be one adult weevil/five seedlings. For a second year stand the threshold is nine to 12 adult weevils/plant.

Overwintering

Adults overwinter in crop debris or in soil cracks.

European Corn Borer

Ostrinia nubilalis

Description

The European corn borer (ECB) was first reported in Saskatchewan in 1949. ECB usually has a single generation in Saskatchewan. Older larvae are flesh coloured with black spots and commonly tunnel in stalks and ears.

Damage

There are five larval instars. The first two instars are whitish with black heads and feed within the whorl, causing shothole and window pane damage. The first two instars complete development in seven to ten days. The third instar larvae bore into the stalk. Once inside the stalk, it is too late to achieve chemical control.

The later instars (third to fifth) feed within the stalk and ear shanks, disrupting the normal movement of nutrients, which results in decreased yield. Tunneling and boring may permit secondary infection and damage by rotting of the stalk and ear.

Scouting

Should begin in late July to the end of August. Economic thresholds vary.

Management of ECB starts with corn product selection. Products with the *Bacillus thuringiensis (*B.t.) corn borer trait have provided control of ECB. B.t. corn hybrids produce an insecticidal protein derived from the bacterium *Bacillus thuringiensis*. Managing corn residue to reduce overwintering can also greatly reduce ECB numbers as well as crop rotation. Scouting for frass piles (excrement) will provide an indication that larvae may be present.

Economic Threshold

There is no straightforward economic threshold for European corn borer, as it varies based on factors such as the type of corn grown, cost of control methods, and value of the corn's grain or feed. Early scouting is required if chemical control measures are used as second instar larvae tunnel into the plant and are untreatable. Early control may be warranted if 50 per cent of plants show shotholes or windowpanes.

Overwintering

Mature larvae overwinter in corn stalks, cobs and plant debris on the soil surface.

Figure 3.76 Shot holes in corn

Figure 3.77 Poor ear development in corn

Figure 3.78 Shot holes in kernels

Figure 3.79 Stalk lodging in corn

Figure 3.80 Scouting for frass piles (excrement)

Figure 3.81 Later (third to fifth) instar

Figure 3.82 Adult corn borer moth

Figure 3.83 Monitoring trap for ECB adult moths

Insect Pests of Multiple Crops

Alfalfa Caterpillar

*Colias eurytheme (*Boisduva)

Description

Adult butterflies can be white, yellow, or orange with a distinguishing black border on the upper surface. Mature larvae are green caterpillars with a prominent white stripe along each side that has a fine reddish line in the middle. They can be up to 30 mm in length and are velvety in appearance.

Damage

Adults feed on flowers for their nectar. Larvae feed on soybeans, alfalfa, vetch, milkvetch and trefoil as well as sweet and white clover causing defoliation.

Scouting

There are two generations per year. The first larvae normally start showing up in mid-May and the second-generation mid-June.

Economic Threshold

There have been no thresholds established, however, in most years this pest is controlled by natural predators. Pathogenic fungi and a naturally occurring virus along with spiders also serve to keep these pests in check.

Overwintering

Adult alfalfa butterflies fly in from central North America during summer.

Figure 3.84 Alfalfa Caterpillar feeding on soybean

Aphids

Brevicoryne brassicae L. - Cabbage aphid
Lipaphis erysimi (Kaltenbach) - Turnip aphid
Rhopalosiphum maidis (Fitch) - Corn leaf aphid
Rhopalosiphum padi (Linnaeus) - Oat-birdcherry aphid
Schizaphis graminum (Rodani) - Greenbug
Sitobion (Macrosiphum) avenae (Fabricus) - English grain aphid

Description

Aphids are small soft-bodied insects that are a pest of several crops in Saskatchewan including wheat, barley, oats, rye, canary seed, canola, forages and legumes. They feed on the sap by piercing plant tissue on the underside of leaves and flower buds. Their rate of reproduction is very high during the spring and summer and each phase of aphid matures quickly, allowing for multiple generations of aphids in one season. Aphids are also food for many beneficial insects.

Aphids of concern have varying identifying characteristics; body colour, antennae, cornicles and cauda will be the main characteristics to identify which species you are dealing with.

Damage

Aphids damage the host plant by sucking sap, damaging stems, leaves or flowers, causing abnormal growth, wilting or flower drop.

In canola, the damage is rarely significant in Western Canada since most of the pod formation is completed prior to aphid populations developing, and the few damaged young green pods contribute very little to overall yield. However, some damage may occur during bud formation and into flowering and may impact seed set and quality.

In cereals, no visual symptoms are noticeable from some aphid species, but heavy infestations may impact protein and test weight in wheat. Oat-birdcherry aphids are also vectors of barley yellow dwarf virus which can stunt barley and oats. Greenbug damage in cereals may leave discolouration, wilting, and spotting at feeding sites.

Scouting

Canola is most sensitive to aphid damage during bud formation through late flowering. Crops at these stages should be checked regularly for aphids in case numbers escalate enough to cause economic damage to the crop. Aphid distribution can be patchy. Check at least five points of the field and look for aphids on a minimum of 20 plants at each point. Check plants and count the number of flowers or stems infested with aphids.

In cereal crops, scout for aphids prior to the soft dough stage. While scouting, use a sweep net or tap plants into a tray or bucket to get an indication of aphid presence and abundance. If numbers are high, conduct a more thorough examination. Count aphids on 20 randomly selected stems in five different areas of the field. Counts should be at least 50 metres apart and observations should be taken in the middle of the field as well.

While scouting, you may encounter mummified aphids who have been parasitized and have died.

Figure 3.85 Labelled aphid body

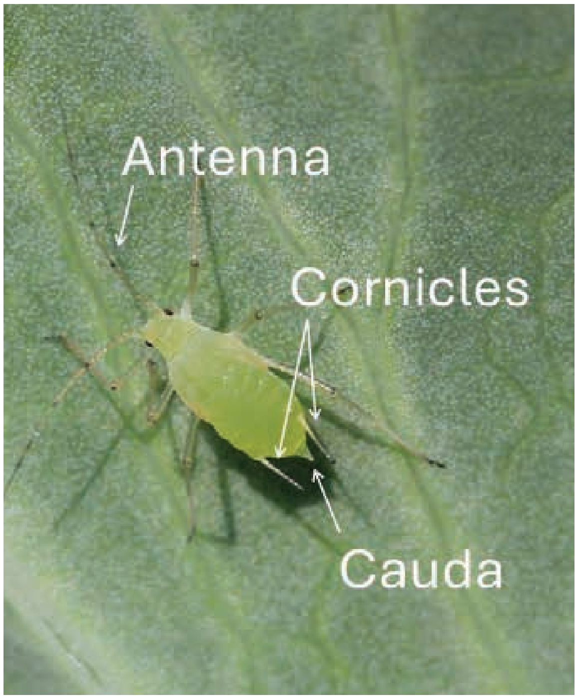


Figure 3.86 Aphids on canola stem during flowering

Economic Threshold

Canola: Aphids rarely cause economic damage to canola unless their population is extraordinarily high. If 10-20 per cent of the stems are infested with colonies of aphids in flowering to early pod stages, or 25 aphids/10 cm shoot tip after flowering, control measures should be considered to avoid yield losses. Factors that increase the risk of economic yield losses are poor finishing rains or crops already being under some degree of drought stress.

Cereals: 12 to 15 aphids per stem prior to soft dough stage.

Cereal Aphid Manager® is a mobile app that helps determine populations by predicting what the population will be in seven days, along with beneficial insect pressure on the population and suggests if insecticide application is necessary. Look for the Cereal Aphid Manager in your phone's app store.

Overwintering

Overwinter as eggs.

Figure 3.87 Cluster of aphids on oat flag leaf and sheath

Figure 3.88 Aphids on wheat spike

Figure 3.89 Live and mummified aphids under a canola leaf

Aster Leafhopper

Macrosteles quadrilineatus (Fbs.)

Description

Adults (3.5 - 4.0 mm) are light green to yellowish green with paired spots on the head. They have smoky-grey wings. Aster leafhopper nymphs look similar but don't have wings. Leafhoppers tend to walk slightly sideways.

Damage

They transmit aster yellows. Feeding occurs earlier in the season with symptoms becoming visible later on.

The active, jumping insects often fly up when disturbed in the crop canopy.

Scouting

Although sweep nets are used to gather aster leafhoppers, they are not used as a scouting method because there is no economic threshold. Numbers collected in a sweep net do not necessarily reflect potential damage caused by the pathogen they can carry.

Figure 3.90 Aster leafhopper

Courtesy of: AAFC

Figure 3.91 Aster leafhopper on wheat awn

Susceptible Crops

Aster yellows symptoms are most prominent in canola and camelina. Flax plants also show noticeable symptoms. The disease commonly infects cereals but symptoms are more difficult to detect. Aster leafhoppers prefer cereals as host plants over canola. The relative preference of host crops is barley > wheat > canola.

Economic Threshold

There is no economic threshold for aster leafhoppers because applying insecticide after symptoms appear is not cost-effective.

Overwintering

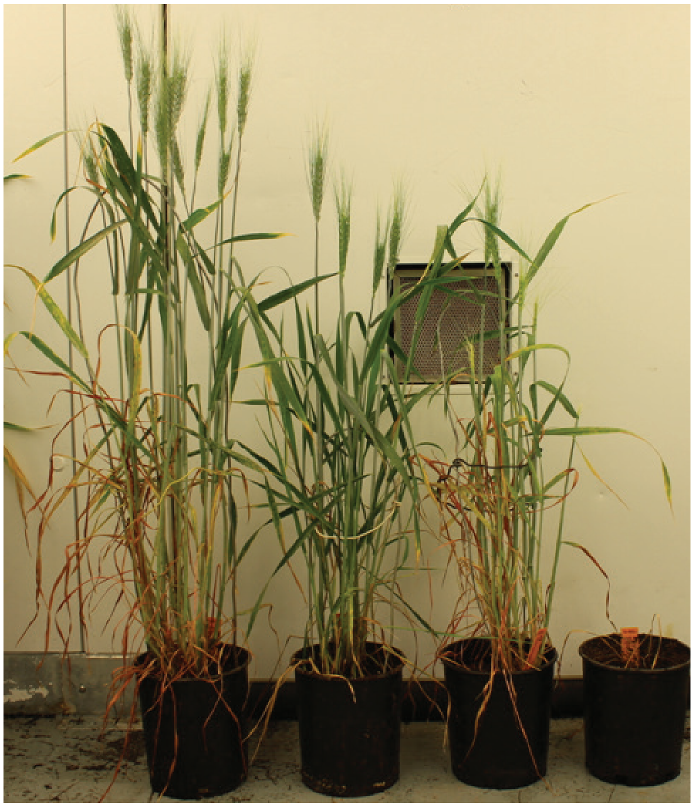
Very few, if any, adults manage to overwinter in the Canadian Prairies. Adults arrive from the US in mid May to mid June on southerly winds.

Figure 3.92 Aster yellows in canola

Figure 3.93 Aster yellows in flax

Figure 3.94 Aster yellows on canola pod

Figure 3.95 Aster yellows in durum



Courtesy of: AAFC

Left-Sliding scale of aster yellow effects in strongfield durum from least affected to most affected (left to right). The first three plants show signs of purplish and reddish leaves and shorter stature plants. The last plant was infected early on, stayed dwarfed and did not produce heads.

Figure 3.96 Aster yellows in sunflower

Blister Beetles

Lytta nuttalli-Nuttall's blister beetle
Epicauta pennsylvanica-Black Blister Beetle
Epicauta fabricii-Ash grey blister beetle

Description

Larvae go through a complex series of development states referred to as 'hypermetamorphosis'. Adults vary in size between 12-25 mm depending on species. Their pronotum or 'neck' is narrower than their head and abdomen. They have chewing mouthparts. They overwinter as pseudopupae in the soil. Females lay four or five batches of eggs in the soil which take two to three weeks to hatch.

Damage

Nuttall's blister beetle larvae feed on solitary bee larvae and on the food bees have stored for their own larvae. *Epicauta* spp. triungulin larvae will feed on grasshopper eggs. Black blister beetle adults feed mostly on alfalfa flowers but will also consume leaves. Blister beetles have cantharidin in their haemolymph (blood) that can cause blistering if it comes in contact with skin.

Scouting

Adults can easily be seen feeding on alfalfa plants. Blister beetles may also be found in soybean, faba bean, canola, sweet clover, potato and sugar beet fields. Blooming alfalfa fields are very attractive to adult blister beetles. To reduce the chance of contaminating hay with dead beetles, cutting should occur at early five to 10 per cent bloom stage. Adults will also feed on pigweed species and kochia.

Economic Threshold

No thresholds have been established. Blister beetles produce the defensive compound, cantharidin that is toxic to horses. Four to six grams (roughly 65 beetles) can be dangerous to a full-sized horse.

Overwintering

Larvae overwinter in the soil.

Figure 3.97 Black blister beetle

Figure 3.98 Nuttall's blister beetle

Figure 3.99 Grey blister beetle

Cutworms

Euxoa ochrogaster (Guenée)-Redback cutworm
Agrotis orthogonia (Morrison)-Pale western cutworm
Feltia jaculifera (Guenée)-Dingy cutworm. *F. subgothica* and *F. herilis* are included in this complex

Description

There are several varieties of cutworms in Saskatchewan that are economically important and have a variety of host crops. Cutworm larvae typically have six instars before they are fully grown. Mature larvae burrow into the soil to pupate.

Damage

Plants (weeds or crop) appear notched, wilted, cut-off or completely missing. Damage is often patchy in a field.

Scouting

Check seedlings on a weekly basis from mid-May to mid-June. Feeding occurs at night. During the day, cutworms may be found in soil near damaged areas.

Economic Thresholds (redback and pale western)

Five to six larvae per square metre in cereals and grain corn, four to five larvae per square metre in flax and canola, two to three per square metre in peas, one small larva per metre of row in soybean and dry bean.

Overwintering

Overwinter as eggs and larvae.

Figure 3.100 Dingy cutworm

Figure 3.101 Dingy cutworm adult

Figure 3.102 Redback cutworm

Figure 3.103 Cutworm damage on soybean

Figure 3.104 Cutworm damage on faba bean

Courtesy of: Saskatchewan Pulse Growers

Field Cricket

Gryllus pennsylvanicus

Description

Field crickets can be beneficial insects as they feed on flea beetles, grasshopper eggs, aphids, etc. There are instances where field crickets can become crop pests when they feed on the seeds of cereal and forage crops. Common weed hosts of field crickets include lamb's quarters, plantain, crabgrass, and ragweed. Adult field crickets are dark brown or black and are approximately 15-25 mm long with small brown wings.

Damage

When field cricket populations are high and lots of feeding is occurring, seed yields in cereal crops can be reduced.

Scouting

No scouting techniques have been developed for this pest.

Economic Threshold

There is no established economic threshold for field crickets, and their control is managed on a case-by-case basis depending on factors such as crop type, crop condition, population size, and extent of damage.

Overwintering

Adult female crickets lay eggs in the soil in August and September, and the eggs overwinter in the soil. In the spring, eggs hatch and nymphs develop early in summer. Nymphs will mature into adults throughout the summer months. There is only one generation of field crickets per year.

Figure 3.105 Cricket in canola crop

Figure 3.106 Cricket

Grasshopper

Most Common Species:

Melanoplus bivittatus (Say) - Two-striped grasshopper
Melanoplus packardii (Scudd) - Packard's grasshopper
Melanoplus sanguinipes (F.) - Migratory grasshopper
Camnula pellucida (Scudd) - Clear-winged grasshopper

Description

Eggs are laid in a foam that hardens into a tough case that's 1 to 3 cm in the soil and looks like brown rice. Egg hatching can extend over four to six weeks, depending on species and temperature.

Grasshoppers go through five nymphal instars before they become mature adults with wings. The colours of the immature stages can be variable as they develop.

Damage

The major pest species have different host preferences. Two-striped grasshopper, the most prevalent pest species in Saskatchewan in recent years, prefers lush foliage but will feed on cereals. Packard's grasshopper prefers legumes and thistles, migratory grasshoppers have a very broad host range. Clearwing grasshoppers prefer grasses. Any of these species can cause severe damage to crops within their host ranges as nymphs or adults when in sufficient numbers.

Scouting

Begin scouting in late May or June when pest species hatch. Walk through field margins and observe number of grasshoppers jumping along a transect. Look for damage along the field margins.

Summiting Disease

Grasshoppers are subject to a natural fungal disease caused by the pathogen *Entomophaga grylli*. The disease is commonly known as summiting disease. Grasshoppers contract the disease by feeding on plants with these fungal spores. Infected grasshoppers will climb to the top of a plant and "death-grip" the plant until they die. The grasshopper's body will release fungal spores when it decomposes, spreading the pathogen. Summiting disease is most common in warm humid conditions in the summer. Although the pathogen causing the disease is not a biological control method, it is good to scout for the occurrence of this disease if populations are high. It is important to note the disease has various isolates, potentially impacting only specific pest species of grasshoppers in a year.

Economic Threshold

Varies by crop. Typically ten to twelve per square metre in most crops. Canola and soybean are tolerant of foliar feeding so thresholds are about 14 per square metre. Flax in the boll stage and lentils that are podding are more sensitive to their feeding so two per square metre should be used.

Field margin thresholds (including ditches) are 50-75 nymphs per square metre and 21-40 adults per square metre.

Overwintering

All pest species in Saskatchewan overwinter as eggs.

Figure 3.107 Two-striped (left) and packard (right) grasshopper

Courtesy of: Dan Johnson

Figure 3.108 Two-striped grasshopper adult

Figure 3.109 Grasshopper infected with summiting disease

Figure 3.110 Clear-winged grasshoppers second/third instar

Figure 3.111 Migratory grasshopper

Figure 3.112 Two-striped grasshopper, first instar

Figure 3.113 Two-striped grasshopper, second instar

Figure 3.114 Two-striped grasshopper, third instar

Figure 3.115 Encapsulated grasshopper eggs

Figure 3.116 Uncovered grasshopper eggs. Phone to give perspective to size

Grasshoppers in Saskatchewan

Their hind legs are marked with a series of black bands.

They have a spur on thier throat.

They have two light-coloured stripes that extend from just behind the eyes but don't continue down the wings.

Their forewings are uniformly grey and lack distinctive stripes.

Adults are brownish or greenish with black or brown markings.

Two pale stripes extending back from the eyes to the tip of the forewings.

They are yellow to brown, have mottled forewings and transparent hindwings and light stripes that converge.

They have a characteristic camouflage pattern on their hindwings.

THREE TO FOUR SPECIES OF GRASSHOPPERS ARE PESTS

If they have wings before late June, they are not a pest. *Wings in the spring, not a pest.*

If they have brightly-coloured hind wings they are not a pest.

NOT PESTS

To view webinars on grasshoppers in Saskatchewan, visit @AGSaskWebinars on YouTube.

Grey Garden Slug

Deroceras reticulatum

Description

This slug species was accidentally introduced from Europe. Adults can be 5 cm. The head has two sets of tentacles: the upper pair is equipped with eyes and the shorter, lower tentacles, have sensory cells used for smelling and tasting. They can range from grey to brown and are more likely to be an issue in cool wet conditions.

Damage

The mouth of a slug features a toothed rasp called a radula. They use this to rasp plant tissues. Although they can damage seedling crops, they are typically associated with mature crops on the Canadian prairies, particularly in wet years following a mild winter. They have a very broad host range and can consume several crops including canola, wheat, barley, corn, legumes and potatoes. Most reports of grey garden slugs have been in canola. They will consume foliage, pods, entire seedlings, as well as tubers and roots

Scouting

Typically, field slugs are more common in wet conditions. As they prefer cooler temperatures, they can generally be found feeding from dusk until dawn. Scouting should be performed during the evening as slugs will climb up the plants to feed. Juvenile slugs can be difficult to spot. They lay their small orb-like eggs near the surface of the soil or slightly buried.

Economic Threshold

There is currently no economic threshold. Bait options are available for minimal control, while foliar options seem ineffective. Tillage may be an effective way in controlling slugs for the following season.

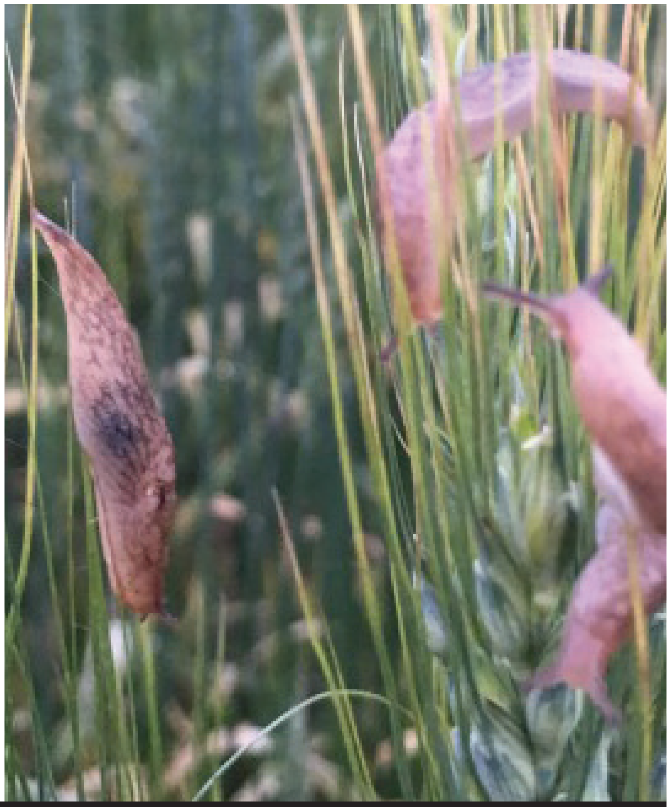
Overwintering

These eggs can overwinter in the straw residue.

Figure 3.118 Grey garden slug

Figure 3.117 Field slug damage

Figure 3.119 Grey garden slug



Lygus Bugs

Lygus elisus (Van Duzee) – Pale legume bug
L. lineolaris (Palisot de Beauvois) – Tarnished plant bug
L. hesperus (Knight) – Western tarnished plant bug
L. keltoni (Schwartz)
L. borealis (Kelton)

Description

Lygus bugs infest multiple crops grown in Saskatchewan including canola, faba bean, soybeans and alfalfa. They pose a substantial threat to faba bean production grown for human consumption due to grading factors that are very strict for lygus bug damage. In the southern regions of the prairies, the first-generation adults appear at the end of June. There can be two generations of lygus bugs in the southern part of the province and one in the northern regions. The central region will experience a partial second generation if conditions are warm and dry.

Lygus bug nymphs are green, small and wingless and move quickly when disturbed. Nymphs go through five instars before molting into adults. Mature nymphs have similar colouration to adults but with black dots on their backs. Wing buds can be noticed.

Adults are 6 mm long and vary from pale green to reddish brown to black. They can have a uniform colour or mottled colour and display a triangular or "V"-shaped mark on the upper centre of their backs.

Damage

Lygus bugs, including both adults and nymphs, feed on new plant growth, flower buds, seeds, and pods by piercing plant tissues to extract fluids. This feeding causes flower and pod drop, and when feeding on buds, they turn white and fail to develop. In canola, buds appear bleached and shrunken, and when feeding on pods, lygus bugs suck out the seed contents, leading to dark spots on the seeds that can result in downgraded quality and yield loss. Females lay eggs in stems, leaf midribs, and petioles, and adults continue feeding into late summer before moving to overwintering sites.

Scouting

Scouting for lygus bugs should begin in mid-July using a standard 15-inch sweep net, with 10 180-degree sweeps at 10 different spots in the field. Regular scouting is essential, including in representative areas and thicker parts of the field. Edge sampling is useful in years when thick crop growth makes it difficult to access the field, but the sampled area should match the crop stage of the main field to ensure accuracy.

In regions where precipitation exceeds 100 mm from bud formation to the end of flowering, canola may partially recover from lygus bug damage. Recent research also suggests that canola can compensate for low lygus numbers (one or fewer per sweep), reducing the impact of minor infestations.

Figure 3.120 Adult lygus bug showing distinctive "V" shaped marking

Figure 3.121 Adult tarnished plant bug on canola plant

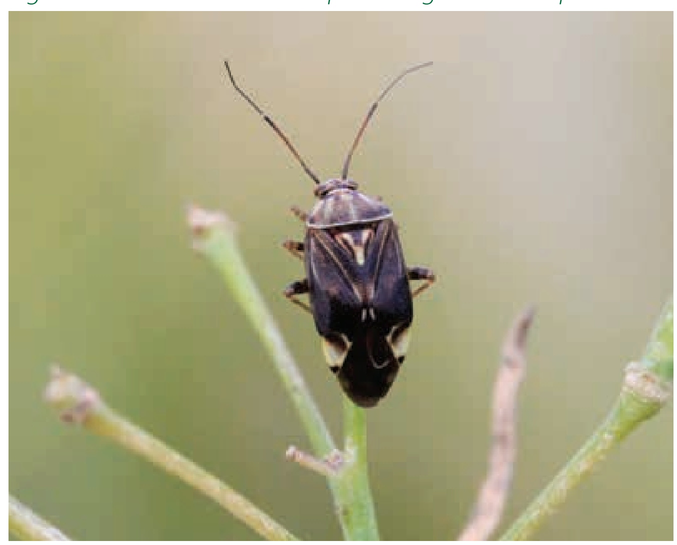


Figure 3.122 Lygus bean damage in faba bean

Economic Threshold

Canola: A threshold of 20-30 lygus bugs per 10 sweeps is suitable for good growing conditions. Include mature nymphs in counts. Using the lower end of the threshold (20 per 10 sweeps) may be appropriate for stressed canola with less ability to compensate for feeding. When most pods become leathery and when seeds are firm, lygus bugs can no longer penetrate the pods or seeds with the mouth parts and are no longer an economic threat.

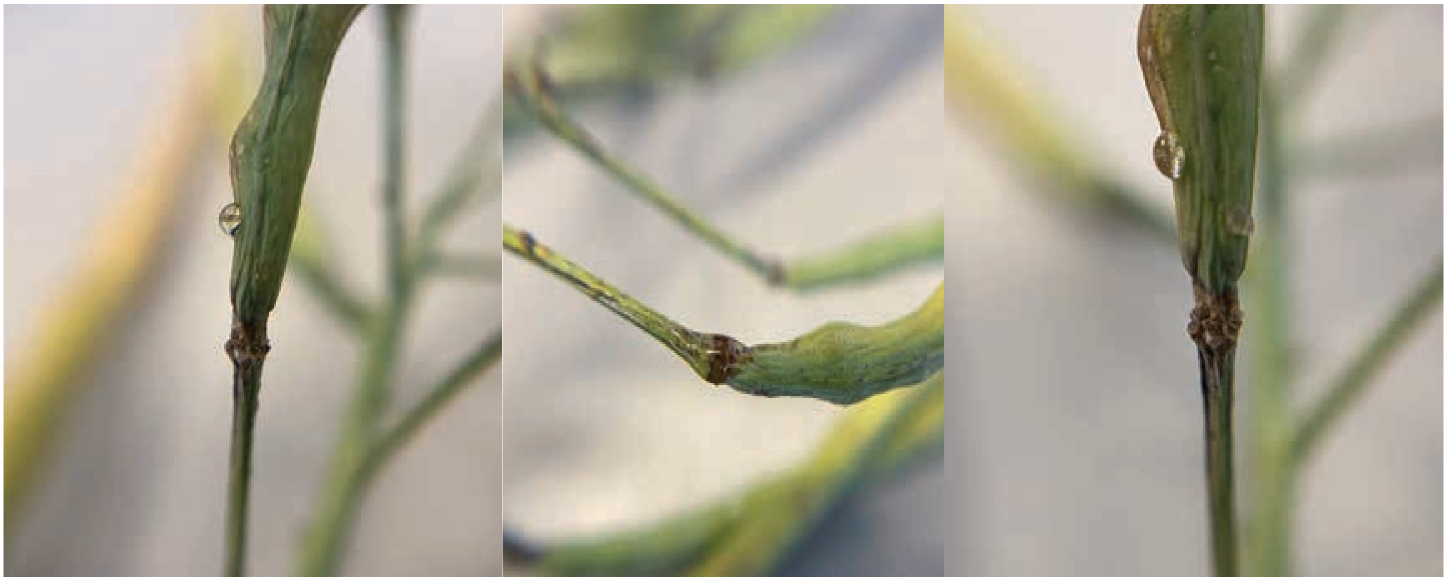
Alfalfa: A threshold of four to five lygus bugs/sweep at bud and early bloom for seed production.

There are no current economic thresholds for lygus bugs in faba bean, but there is Saskatchewan-based research being conducted to establish threshold numbers.

Overwintering

Lygus bugs overwinter as adults by finding shelter under plant litter in shelterbelts, headlands, uncultivated areas, and field margins and emerge from hibernation once the snow melts in the spring.

Figure 3.123 Damage from lygus bugs on canola pods



Meadow Spittle Bug

Philaenus spumarius

Description

It is the nymphal stage of the meadow froghopper. As a nymph feeds on the plant's xylem using its piercing sucking mouthparts, fluid is excreted through the nymph's anus along with a sticky substance from its abdominal glands. The nymph then uses its tail to whip air into the mixture producing the foam mass. The foam flows around the nymphs' body encasing it. This is a continuous process as the spittlebug feeds on the plant. It protects the spittlebug from predators, parasitoids, dry weather and ultraviolet radiation. A mass of foam may contain just one spittlebug or dozens. There are five nymphal instars, and each nymph will feed for one to three months. The last instar will develop wing pads and darken before maturing into an adult.

Damage

It is the nymph or spittlebug stage that can cause early season damage to alfalfa, clover, wheat, oat or corn stands although research shows there are over four hundred species of plants that they feed on. When a large number of nymphs are present, they can cause stunting of plants which can result in possible substantial yield losses. With alfalfa, damage is generally most severe on first year alfalfa fields that were planted in small grain stubble.

Adult froghoppers generally do not cause crop damage, however, like the nymphs they feed by piercing into the plants tissue. These puncture wounds do provide excellent sites for other plant pathogens to use as points of entry into the plant. Fortunately, there is only one generation a year.

Overwintering

Female froghoppers may mate several times with different males and the offspring of a single female may be fathered by several males. They will lay their eggs in late summer and early fall on plants or by splitting a plant stem and depositing their eggs at the leaf sheath. Egg laying is induced by short day lengths and cooler temperatures. These eggs will overwinter and require a cold period of roughly 100 days when temperatures are less than 5 C.

Figure 3.124 Meadow spittle bug

Figure 3.125 Meadow spittle bug

Stink Bugs

Chlorochroa uhleri - Uhler's stink bug
Euschistus servus - Brown stink bug
Acrosternum hilare - Green stink bug
Aelia americana - no common name

There are beneficial stink bugs as well as damaging ones. The Yellow Spotted Stink Bug and Brown Marmorated Stink Bug are two species that we are watching for in Saskatchewan that are invasive and could be damaging to a variety of crops.

Description

Stink or shield bugs belong to the order of true bugs. Their name is a reference to the smell they emit when disturbed or squashed. They have a life cycle of egg, nymph, and adult stages. Females lay their eggs in clusters on the undersides of leaves and stems. Once they hatch, wingless nymphs will moult several times before they become winged adults. They usually complete only one life cycle in northern climates.

Damage

With their piercing sucking mouthparts, stink bugs feed on stems, leaves, fruit and developing seeds. These species have broad host ranges. While soybeans and field corn are crops of choice for both nymphs and adults, they have also been found feeding on cereals, canola, pea, and sunflower. Shriveled seeds and flattened pods result when they feed on soybeans while discoloured and shrunken kernels will be found on corn and cereals. If soybean fields are heavily infested in late summer to early fall, fields can display a "stay green" syndrome due to a delay in ripening.

Scouting

Feeding damage generally starts in the outer 10-12 metres of a field and moves inward.

Economic Threshold

There are no established economic thresholds for stink bugs.

Overwintering

Stink bugs overwinter in tree barks or get into homes/shelters to survive the winter.

Figure 3.126 Brown stink bug nymph

Figure 3.127 Brown stink bug

Figure 3.128 Stink bug feeding on corn

Figure 3.129 Stink bug

Figure 3.130 Stink bugs on soybean

Thistle Caterpillar aka Painted Lady Butterfly

Vanessa cardui (L)

Description

Thistle caterpillars have a range of hosts including Canada thistle, sunflowers, canola, mustard, borage, soybeans, and many other hosts. Adults are medium-sized butterflies with pointed wings spanning 42-66 mm. Their wings are orange with black and white markings on the upper surface. Mature larvae (40-45 mm long) have a black head and are yellowish-green or purple-mottled with black and a broad white stripe along each side. They also have many longer yellow spines.

Damage

Adults feed on the nectar of flowers. Larvae feed together anywhere on a plant in conspicuous leaf nests.

Scouting

If butterflies are very abundant, inspect the crop weekly until caterpillars are noticed feeding on the plants. They are usually heavily parasitized and subject to bacterial disease. Many birds, rodents, dragonflies, wasps and spiders attack the larvae and adults.

Economic Threshold

Specific economic thresholds have not been developed for specific crops, nominal thresholds have been suggested based on the defoliation of sunflowers and soybeans.

Soybeans: Defoliation of 50 per cent at vegetative stage, 40 per cent at bloom, 20 per cent bloom-pod fill and 35 per cent at pod fill-harvest.

Sunflowers: Control may be warranted if 25 per cent defoliation has occurred and most of the larvae are less than 3 cm long. If mature larvae are present, most damage would have occurred already.

Overwintering

Migrate into the Prairies from overwintering sites in Southern California and Mexico.

Figure 3.131 Adult stage is the painted lady butterfly

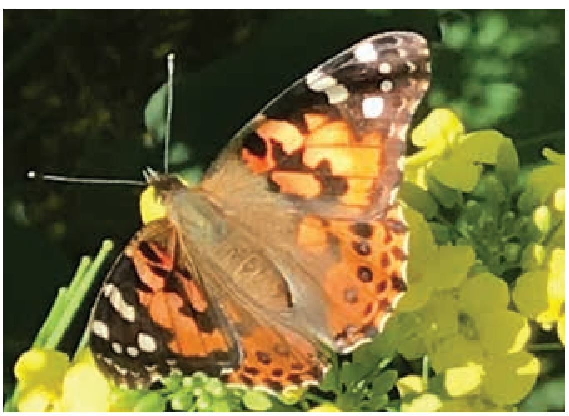


Figure 3.132 Painted lady butterfly larvae

Figure 3.133 Leaf nest in soybeans

Figure 3.134 Thistle caterpillar

Wireworms

Aeolus mellilus-Flat wireworm
Agriotes mancus-Wheat wireworm
Hadromorphus glaucus-no common name
Hypnoidus bicolor-no common name
Limonius californicus-Sugarbeet wireworm
Selatosomus aeripennis destructor-Prairie grain wireworm

Figure 3.135 Wireworm on canola stem

Description

Wireworms are the larval stage of click beetles, and it is during this stage that they cause crop damage. They are a generalist pest, feeding on multiple crops but cause the most damage in cereals and canola. These larvae are hard-bodied, varying in shades of yellow or brown, and measure 1 to 3 cm in length with three pairs of legs. The larval stage can live in the soil for four to 11 years before pupating in July. Both larvae and adult click beetles overwinter in the soil, with larvae capable of surviving up to two years without food, surviving only on humus. Multiple generations can occur in a field, and regional differences in species behavior can exist. Therefore, effective wireworm control needs to be tailored to the specific pest species and environment found in each region.

Damage

Larval feeding occurs below ground.

Scouting

Look for bare and/or thin areas in a field. Dig up seedlings to examine for shredded stems as this may be an indication of a wireworm problem. Comparatively, cutworm damage will be different as they usually cut off the entire stem. Germinating seeds give off carbon dioxide which causes wireworm larvae to move up through the soil profile to feed on germinating seeds or young seedlings.

Burying baits made of cereal balls or raw potatoes about 10-15 cm deep in the soil, leaving them for about a week and then digging them back up can give an indication to species and how prevalent they are.

Economic Threshold

Official thresholds have not been established for wireworm numbers in canola or cereals. Seed treatments formulated for wireworm protection are the best preventative measure. Cultural practices include keeping summer fallow fields free of green growth during June-July to starve out newly hatched larvae. Additionally, including non-host crops within your crop rotation may help to reduce egg-laying and larval development.

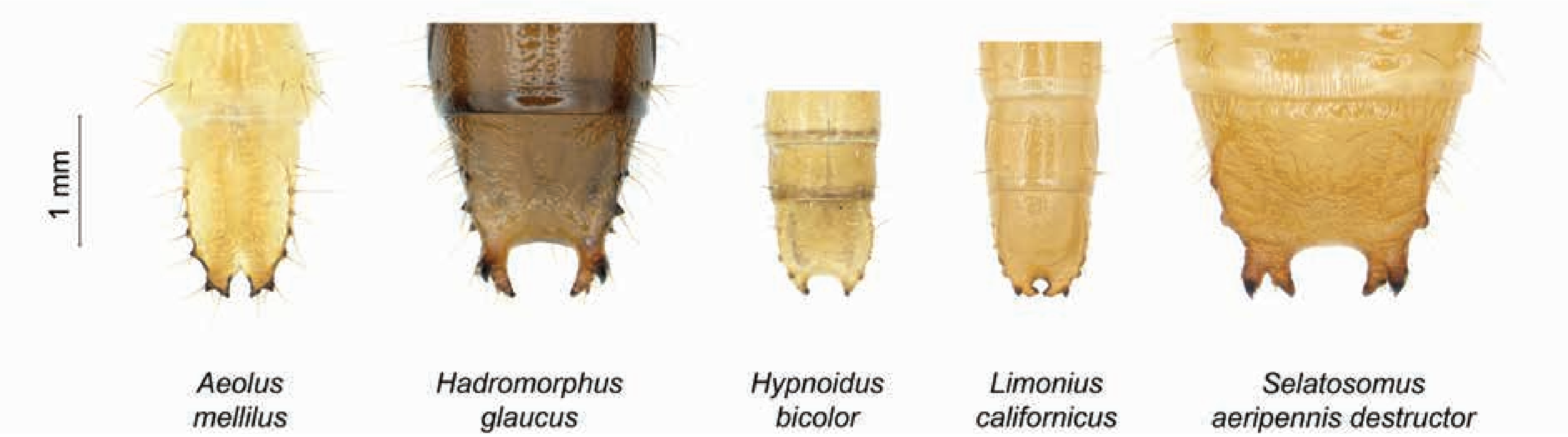
Overwintering

Adult click beetles overwinter in the soil.

Figure 3.136 Five wireworm species

Courtesy of: AAFC

Figure 3.137 Caudal segments of different wireworm species



Courtesy of: AAFC

Figure 3.138 Wireworm damage in canola

How to Use a Sweep Net

Sweep nets are used to collect insects that are difficult to see in a crop canopy. Sweeping allows you to count and identify the insects that are currently found in the crop. A typical sweep net is 38 cm (15 inches) in diameter.

Pick undisturbed areas of the field to sweep. A sweep is made by swinging the net firmly through the crop canopy. One sweep should be a 180 degree pass (unless a 90 degree sweep is specified); take at least one complete step forward between sweeps to get a better representative catch.

Figure 3.139 Sweeping diagram

After the last sweep, instantly swing the net back and forth rapidly through the air, well above the canopy, to force the insects to the bottom of the net. Shaking the net rapidly, after the last sweep, is another option to gather the insects at the bottom of the net.

Once the insects have fallen deeply in the sweep net, grab the net approximately 15 to 20 cm from the bottom to prevent insects from escaping. Invert the net through the rim of the net to put the insects in a clear bag for close identifying or counts.

Note: Sweep nets can be ordered through Pro Metal Industries Ltd. in Regina, Sask. (306)-525-6710, sales@prometal.ca.

Sweep Net Tips

- Sweeping an increased number of locations in the field will give a better idea of what composition of insects are in the overall field. Pick different spots to sample throughout the field and be careful not to overemphasize field margins as they can be quite different from the rest of the field.
- Sample bags containing sweep samples can be sealed and frozen for counting later if the insect of interest is hard bodied such as the cabbage seedpod weevil, but not immature larvae.
- The best time to survey for most insects is during the day when the temperatures are not too cold but not extremely hot either. Windy conditions will also affect sampling as insects may move lower in the canopy or drop to the ground until conditions improve. Monitoring time will depend on the insect.
- When buying or making a sweep net, make sure the hoop, as well as the handle, are strong and well secured for sweeping through heavy crops. Butterfly nets are not recommended for use as a sweep.

Figure 3.140 Example of using a sweep net in wheat

Economic Thresholds

Table 3.2 Economic thresholds for various insects and crops

Crop	Insect	Economic Threshold
Canola	Flea beetles	25% of the cotyledon surface is destroyed and flea beetles still present. If damage is only along field margins, and beetles are still congregated there, then control measures should be applied to the damaged areas only.
	Grasshoppers	10-14/m^2 if damage is being caused.
	Cutworms	Threshold of a 25-30% stand reduction. It is economical to just treat infested patches, and not whole fields.
	Diamondback moth	Threshold of 100-150 larvae/m^2 in immature to flowering plants, based on 150-200 plants/m^2 200-300 larvae/m^2 in plants with flowers/pods, based on 150-200 plants/m^2
	Bertha armyworm	Refer to Table 3.1 on page 84.
	Cabbage seedpod weevil	25 to 40 weevils per 10 sweeps.
	Aphids	Control may be justified when at least 10-20% of the stems are infested with a cluster of aphids in flowering to early pod stages or 25 aphids/10 cm shoot tip after flowering. Rarely an economic issue in Saskatchewan.
	Lygus bug	A threshold of 20-30 Lygus bugs per 10 sweeps is suitable for good growing conditions. Using the lower end of the threshold (about 20 per 10 sweeps) may be appropriate for stressed canola with less ability to compensate for feeding. When most pods become leathery and when seeds inside are firm, lygus bugs can no longer penetrate the pods or seeds with their mouth parts and are no longer an economic threat.
Flax	Aphids	3 aphids/main stem at full bloom. 8 aphids/main stem at green boll stage.
	Cutworms	4-5 larvae/m^2. Sometimes it is most economical to just treat infested patches, and not whole fields.
	Grasshoppers	2 grasshoppers/m^2 (green boll stage)
Cereals	Aphids	12-15 aphids/stem prior to soft dough stage
	True armyworms	10 armyworms/m^2
	Cutworms	Pale western cutworm 3-4 cutworm/m^2, redback and army cutworm 5-6 cutworm/m^2. Well established fall-seeded crops or spring seeded crops with good moisture conditions can tolerate higher numbers. Sometimes it is most economical to just treat infested patches, and not whole fields.
	Grasshoppers	8 to 13 grasshoppers/m^2. Early in the season, when grasshoppers are small, 18 grasshoppers/m^2 and visible crop damage may be a more appropriate threshold.
Wheat	Wheat midge	Conventional wheat: approximately 1 adult/4-5 heads for yield; 1 adult/8-10 heads for grade
Barley	Barley thrips	Insecticide treatments are only effective when applied before heading is complete. 7-8 thrips/stem prior to head emergence indicates it's time to spray. For more precision, use the following formula: # Thrips/stem = (cost of control/expected $ per bu)/0.4
Canaryseed	Aphids	10-20 aphids on 50% of the stems prior to soft dough stage
Lentils	Aphids	30-40 aphids/sweep, few natural enemies present and when aphid numbers do not decline over a two-day period
	Grasshoppers	2 grasshoppers/m^2 (blooming and podding stage)
Peas	Aphids	If, at the beginning of flowering, there are 9-12 aphids per sweep or 2 to 3 aphids per 8 inch (20cm) plant tip, an insecticide application when 50 per cent of plants have produced some young pods will be cost-effective.
	Pea leaf weevil	30% of seedlings with damage (leaf notching) on the clam leaf during 2nd to 5th node stage. The crop is not susceptible to damage after the 6th node stage or it is too late to attempt control.
	Cutworms	2-3 cutworms/m^2
Alfalfa	Lygus bug	Seed production: 4-5 lygus bugs/sweep at bud and early bloom
	Alfalfa plant bug	Seed production: 4-5 plant bugs/sweep
	Alfalfa Weevil	One of the best control strategies is to cut fields for hay early. If early cutting of the hay crop is not possible, treatment thresholds are based on the following measurements of plant height and levels of larvae. Hay: <30cm plant height, 1 larva/stem; <40cm plant height, 2 larvae/stem; 3 larvae/stem is generally economical to control regardless of crop height. On regrowth for second crop, 2 or more active larvae per crown (4 to 8 larvae per square foot) will require insecticide application Seed: 20-30 third or fourth instar larvae, larvae/sweep (90 degree = straight sweep) or 35-50% leaf tips showing damage. In some cases it may be practical to just treat hotspots and not entire fields.
	Pea Aphid	Seed: 100-200 aphids/sweep (when dryland crop is moisture stressed or until mid-August)
	Potato leaf hopper *	Seed: for <9 cm stem height=0.2 adult leafhoppers per sweep; 9-15 cm stem height=0.5 adults per sweep; 15-25 cm stem height=1 adult or nymph per sweep; 25-36 cm stem height=2 adults or nymphs per sweep
Sweet clover	Sweet clover weevil	1st year stands: 1 adult weevil/3 seedlings (1/5 seedlings under dry conditions) 2nd year stands: 9-12 weevil adults per plant

Sweep refers to a 180 degree sweep with a 38 cm (15 inch) diameter net, unless otherwise noted. Supplementary information can be found in the Guide to Crop Protection
** These insects are rarely found in Saskatchewan.*

Species of Interest

This section focuses on insect species that have either not yet been introduced to Saskatchewan or have been reported only in limited numbers but hold the potential to become significant pests to local crops. If any of these insects are encountered, it is important to report the sighting to your nearest crops extension specialist or directly to Dr. James Tansey at 306-787-4669 or ***james.tansey@gov.sk.ca***.

Brown Marmorated Stink Bug

Halyomorpha halys

Description

The Brown Marmorated Stink Bug has been reported two times in the past in Saskatchewan. They have a broad host range but have not yet become established in the province, although there is potential for them to become so in the future.

The adults are 13 - 17 mm in length and have the shape of a shield. The Brown Marmorated Stink Bug can be identified from other types of stink bug by the brown and white edges of the abdomen. They have distinctive white bands on the antennae, a differentiating feature from other stink bugs.

Damage

The adults will pierce the seeds and suck out the liquid with their specialized mouthparts, resulting in shriveled and damaged seeds. Soybeans and corn are common host crops for stink bug species but have also been found in cereal and oilseed crops as well.

Scouting

Collect samples from the headlands using a sweep net when the pods or seeds are fully developed.

For soybeans, sampling should occur when the pods and seeds are fully mature. In corn, sample during ear formation, while wheat is best sampled during the milk and soft dough stages.

Economic Threshold

None established.

Overwintering

Stink bug species overwinter in tree bark or buildings.

Source: Brown Marmorated Stink Bug (BMSB) Pest Alert - Province of British Columbia (gov.bc.ca)

Figure 3.141 Brown marmorated stink bug

Courtesy of: Biochemtech IPM

Figure 3.142 Brown marmorated stink bug

Courtesy of: Biochemtech IPM

Figure 3.143 Brown marmorated stink bug

Courtesy of: Biochemtech IPM

Figure 3.144 Brown marmorated stink bug eggs

Courtesy of: Biochemtech IPM

Japanese Beetle

Popillia Japonica

Figure 3.145 Japanese Beetle

Description

This species has a broad host range, and Saskatchewan's climate has potential for its establishment which has caused reason for concern. Although it primarily affects fruit and turf, its wide host range could lead to issues in Saskatchewan agriculture.

The eggs of this species are white, oval-shaped, and about 1.5 mm in length, typically found just below the soil surface. The larvae appear as white grubs in the shape of a "C" and feature a distinctive V-shaped end, differentiating them from other grubs. The pupae resemble the adult stage but with folded legs, antennae, and wings. The adult can be identified by its metallic green head, copper-coloured wing coverings, and oval shape, measuring about 10 mm in length and 6 mm in width. They can fly in the wind up to eight kilometres in one flight.

Damage

Adult beetles cause host foliage to appear "skeletonized" by chewing the leaf tissue between the veins. Plants with tougher leaves are less susceptible to damage from Japanese Beetles. However, severe infestations can lead to significant damage, causing leaves to turn brown and defoliate. In areas with 90 or more grubs per square metre, patches of host plants may die off, further harming the plant population.

Scouting

The Japanese Beetle has one generation per year, with adults emerging from late June to early July. They feed on the upper leaf surface of foliage during warm summer days, particularly in direct sunlight. Beetles prefer feeding when the relative humidity is greater than 60 per cent, making these conditions ideal for their activity.

Economic Threshold

The threshold for corn damage is three beetles per ear or when the silks have been chewed down to half an inch. For soybeans, the threshold is 20 per cent leaf defoliation during the reproductive stage and 30 per cent defoliation prior to bloom. These levels indicate when intervention may be necessary to prevent significant damage.

Overwintering

Japanese beetles overwinter as third-instar larvae at depths of two to 12 inches below the soil surface, moving deeper to escape freezing temperatures.

Pollen Beetles

Brassicogethes aeneus

Figure 3.146 Pollen beetle in canola

The pollen beetle is a major oilseed rape pest in Western Europe and is tremendously damaging. It has become established in eastern Canada and should be watched for here in Saskatchewan.

The beetle is about the size of a flea beetle (2 mm) with clubbed antennae and short elytra, both characteristic of the family Nitidulidae.

Swede Midge

Contarinia nasturtii (Kieffer)

Description

The adult swede midge is a small, mosquito-like insect, measuring 1.5 to 2 mm in length and brown in colour. These adult flies emerge from the soil between May and June. The larvae, which are yellow and approximately 2 mm long, are capable of jumping. Originally from Europe, swede midge is an invasive species that is currently causing significant damage to canola production in Ontario. There is concern about the potential for this pest to be established in other regions such as Saskatchewan. Efforts are underway to prevent its spread.

Damage

Larval feeding at growing points causes abnormalities. Depending on the crop stage at time of feeding this can appear as swollen, distorted or twisted young shoots, premature bolting, multiple branching, or "caper-shaped" flower buds that remain closed and are usually green.

Similar species

The canola flower midge (CFM), (*Contarinia brassicola* Sinclair) can be easily confused for the swede midge; however, to date, the only damage symptom associated with CFM infestation is "bottle-shaped" flower buds that remain closed. Scouting can be done when canola is in bloom.

Scouting

Swede midge pheromone traps are available and the most reliable way to positively determine species identification. Swede midge was first identified in Saskatchewan in 2007, but has not been positively identified since this time.

Overwintering

Overwinters in soil in Ontario. Not found in Saskatchewan, yet.

Figure 3.147 Swede midge bud damage

Courtesy of: Jon Williams, AAFC

Figure 3.148 Swede midge larvae feeding

Courtesy of: Jon Williams, AAFC

Yellow Spotted Stink Bug

Erthesina fullo

Description

The Yellow Spotted Stink Bug has potential to be a major canola pest if established in Saskatchewan. Adult Yellow Spotted Stink Bug has a brown/black shield-shaped body with yellowish spots, antennae are black with the fifth section being a light yellow. The body length can vary from 18 - 23 mm.

Damage

Similar to other stink bug species, the yellow spotted stink bug pierces the seeds/fruits of host plants and sucks the liquid out, causing shriveled and damaged seeds.

Scouting

Use a sweep net on the outer edges of the field when the crop has developed seed pods or if there are visual symptoms of stink bug damage.

Economic Threshold

None yet established .

Overwintering

Stink bug species overwinter in tree bark or buildings.

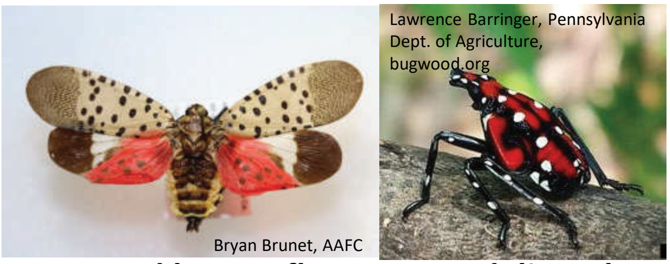
Figure 3.149 Yellow spotted stink bug

Courtesy of: The Noah Project

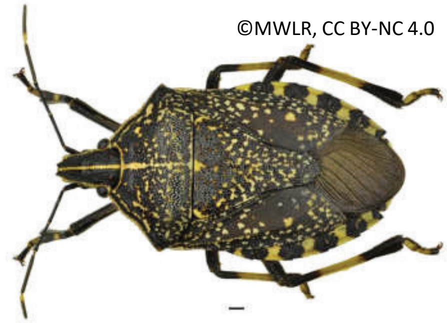
Source: [Biology, Ecology, and Management of Erthesina fullo (Hemiptera: Pentatomidae): A Review - PMC (nih.gov)]

Priority Invasive and Migratory Insects to Report
PRAIRIE REGION

Insects to watch for and report by anyone interacting with insects. Use the QR CODE to report all observations, including species regulated by the Canadian Food Inspection Agency (CFIA).


Bryan Brunet, AAFC
Lawrence Barringer, Pennsylvania Dept. of Agriculture, bugwood.org

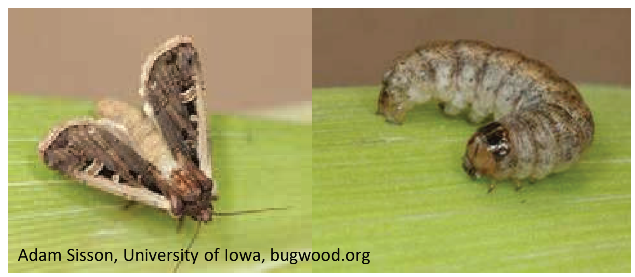
Spotted lanternfly, *Lycorma delicatula*
Hosts: Tree of heaven, grapevine, various (fruit) trees and shrubs
Not present in Canada
CFIA REGULATED


©MWLR, CC BY-NC 4.0

Yellow-spotted stink bug, *Erthesina fullo*
Hosts: Fruits, vegetables, and ornamental plants
Not present in Canada


Susan Ellis, bugwood.org

Brown marmorated stink bug, *Halyomorpha halys*
Hosts: Fruits, vegetables, ornamental plants
Not present in AB, SK, MB


Adam Sisson, University of Iowa, bugwood.org

Western bean cutworm, *Striacosta albicosta*
Hosts: Dry beans, corn, soybean (less preferred)
Not present/established in AB, SK, MB


Karla Salp, Washington State Department of Agriculture, bugwood.org

Spongy moth, *Lymantria dispar*
Hosts: Oak, maple, beech, willow, apple, plum
Not present/established in AB, SK, MB
CFIA REGULATED


Russ Ottens, bugwood.org
Mark Dreiling, bugwood.org

Fall armyworm, *Spodoptera frugiperda*
Hosts: Corn, cereals, forages
Migrant into western Canada

Canada Alberta Saskatchewan Manitoba

V1 2023

Richardson's Ground Squirrel

Description and Damage

Richardson's ground squirrels (RGS) are omnivorous pests and eat forage grasses, forage legumes, cereal crops, pulse crops, canola, and native grasses. They will also consume large numbers of insects and are occasionally cannibals. Damage in crops from RGS ranges from an occasional burrow and insignificant damage to causing significant crop loss, especially when present in large numbers. Crop loss is due to RGS consuming plant material and damaging areas with burrowing. Burrows can also cause equipment damage and livestock injury.

Scouting

Richardson's ground squirrels are above ground from mid-February to October. Adult males emerge in February, followed by females approximately two weeks later. Both sexes are at reproductive maturity at one year old.

Figure 3.150 Baby Richardson's Ground Squirrels. Control is best done before their birth.

Economic Threshold

The economic threshold is the level at which the pest damage exceeds the cost of the management options. Damaged crops and control methods will impact these values. A nominal threshold for RSG is one active mound per four strides or twenty per cent crop damage over 100 metres.

For the best control outcomes, Richardson's Ground Squirrels should be managed in the spring before their young are born, preventing population increases.

Cultural Control

Raptor (hawk or owl) platforms and nest boxes provide nesting sites to natural predators of gophers where natural nesting sites may be limited in the vicinity of ground squirrel infestations. Limit to one raptor platform per quarter section due to territorial behavior.

Chemical Control

Table 3.3 Control options for Richardson's Ground Squirrels

Product	Registration number	Active ingredient	Toxicant effect	Formulation	Notable considerations
Burrow Oat Bait	24795	Zinc phosphide	Central nervous system depressant	Coated oats	Pre-baiting for best results. Not required
ZP Rodent Oat Bait AG	29030	Zinc phosphide	Central nervous system depressant	Coated oats	Pre-baiting for best results. Not required
Rozol RTU Field Rodent Bait	29545	Chlorophacinone	Anticoagulant	Pellet	Re-baiting required after 48 hours. Third baiting may be required
Ramik Green	11669	Diphacinone	Anticoagulant	Pellet	Re-baiting required after 48 hours.

Figure 3.151 Richardson's Ground Squirrel

Figure 3.152 Richardson's Ground Squirrel

Table 3.4 Other toxic baits and rodenticides registered for Richardson Ground Squirrel control

Active Ingredient	Product Name	Per cent Active Ingredient
Zinc Phosphide	Burrow Bait (PCP# 24795)	2.0%
	ZP Rodent Bait (PCP# 14240)	2.0%
	Rodent Bait (PCP# 16122)	2.0%
	Rodent Pellets (PCP# 21838)	2.0%
	ZP Rodent Oat Bait (PCP# 29030)	2.0%
Chlorophacinone	Rozol Paraffinized Pellets (PCP# 13729)	0.005%
	Ground Force Paraffinized Pellets (PCP# 20239)	0.005%
	Poulin's Gopher Doom (PCP# 22608)	0.005%
	Rozol RTU Field Rodent Bait (PCP# 29545)	0.005%
Diphacinone	Ramik Green Rodenticide (PCP# 11669)	0.005%
Aluminum Phosphide	Degesch Phostoxin Round Tablets Rodenticide (PCP# 16351) (Fumigant)	55%
	Gastoxin Aluminum phosphide tablets (PCP# 17187)	57%
	Gastoxin Aluminum phosphide pellets (PCP# 17188)	57%
	Gastoxin Aluminum phosphide tablets (PCP# 23842)	57%
	Gastoxin Aluminum phosphide sachets (PCP# 23843)	57%
	Weevil-Cide Tablets (PCP# 29455)	57%
	Weevil-Cide Tablets (PCP# 30013)	57%
White Mustard seed powder (a) and Sodium Alpha-olefin sulfonate (b)	RoConTMConcentrate Rodenticide (PCP# 27400)	(a) 10.89% (b) 6.91%

Zinc Phosphide

Zinc phosphide is a crystalline, dark powder with a garlic-like odour. It has been around a very long time as a rodenticide. It was first synthesized in the mid-1700s and used as a rodenticide in Italy around 1911–12. It breaks down to produce phosphine when it encounters stomach acid. It works quickly, with onset of symptoms of lethal poisoning apparent within 15 minutes. Death usually occurs in hours. Zinc phosphide continues to break down in rodents that have died, and risks to non-target animals and birds associated with residues are considered relatively low.

Precautions

- Follow all product label directions and precautions.
- Prevent children, pets, and livestock from gaining access to toxic baits.
- Burrow Oat Bait - This can be fatal if swallowed. Wash hands and any skin that may have made contact with the bait thoroughly with soap and water after handling. Wash contaminated clothing separately from other laundry with soap and hot water before reuse. Users should remove clothing immediately if the pesticide gets inside, then wash skin thoroughly and put on clean clothing. Chemical-resistant gloves must be worn when disposing of dead rodents, unconsumed bait, and empty containers. Avoid contact with skin, do not breathe in dust or fumes, do not leave in unprotected piles, and avoid feed and other foodstuffs to prevent contamination.

Anticoagulants

Anticoagulants are separated into two functional groups: first-generation and second-generation. First-generation anticoagulants are used for the control of certain field rodents, including RGS, pocket gophers, and voles. Second-generation anticoagulants can control warfarin-resistant rats and house mice and are also considered single-use feeding anticoagulants.

First-generation anticoagulants (diphacinone and chlorophacinone) used for the control of RGS are multiple-dose rodenticides. These products rely on a cumulative toxic effect. They are substantially more toxic if consumed in small doses over several days than if ingested in a single dose. The baits are formulated so that rodents have to feed a minimum of three to five days before a lethal dose is attained. Death occurs a few days later. In order for the animal to consume enough poison, the bait must be continuously available until the desired control is achieved.

Bait stations or bait boxes need to hold substantial amounts of bait (500 g or one lb.) and must be strategically located so that targeted rodents have access to ample bait for repeated feedings. Bait stations should be designed to prevent access and exposure to non-target animals and be secured to prevent tampering.

The delay in mortality has a safety advantage because it provides time to administer an antidote, if necessary, to treat pets, livestock, and people who may have accidentally ingested the bait. Vitamin K1 is the antidote for anticoagulants. If administered soon after intake, the antidote can reverse the action of the anticoagulant. In addition, the slow action of the anticoagulant baits has another advantage in that the target animal is unable to associate its illness with the bait consumed. Therefore, bait shyness or toxicant shyness does not occur. However, since legumes are a natural source of vitamin K, reduced efficacy can occur if RGS have access to alfalfa or other legume crops.

Most of the anticoagulant baits used currently are commercial ready-to-use formulations. While ready-to-use baits may increase the cost of rodent control, they avoid problems of incorrect bait concentrations and poor bait formulation, which often lead to poor control.

These have been the most commonly used rodenticides worldwide for more than 50–60 years. All anticoagulants have two actions: they reduce the clotting ability of the blood and cause damage to capillaries (tiny blood vessels). The rate of blood clotting gradually decreases, and blood loss leads to an apparently painless death. Repeated daily doses of anticoagulants greatly increase efficacy. Feeding does not have to be on consecutive days, but several feedings should occur within a 10-day interval with no longer than 48 hours between feedings. Ample bait must be made available at all times to achieve adequate control.

Figure 3.153 Damage to canola crop from Richardson's Ground Squirrels

Section 4: Diseases

Sources for this section, unless otherwise noted: Disease descriptions are adapted with permission from Diseases of Field Crops in Canada, 2009, third edition

Seedling Blight, Common Root Rot, Crown Rot and Foot Rot

Cochliobolus sativus
Fusarium spp.

Seedling blight and common root rot complexes are caused by several soil-borne fungal pathogens that are present in the soil across Saskatchewan. These pathogens can affect wheat, barley and oats as well as many other cereals and grasses seen across the prairies. The most common symptoms are brown spots on roots, reduced root development and seedling death. Fungal spores can remain in the soil for many years, waiting for root exudates from susceptible hosts, cool moist conditions and other abiotic stressors that lower the host plant's defensive barriers. Yield loss typically ranges from six to seven per cent each year due to a reduced number of heads and diminished seed size. Overall seed quality is not largely affected. The pathogens can also survive as spores or mycelium in crop residue.

Disease Cycle

Seedling blight is caused by pathogens carried on or in the seed or soil. Most root and crown infections are caused by spores that are already present in the top few centimetres of soil. As infected plants mature and dry down, lots of spores are produced, especially at the crown. On stubble, spore production continues as long as moisture and temperature allow. Spores or infected pieces of plant tissue can spread by wind, rain, surface water and equipment. These spores remain dormant in the soil and can cause new infections when conditions are right.

Figure 4.1 White wheat head symptom of root rot

Symptoms and Scouting

The first sign of an issue is poor seedling emergence creating bare patches throughout the field. If seedlings do germinate, they might not survive long enough to emerge, or they will emerge but become brown, pinched and eventually die. Other symptoms include stunted growth, yellowing and reduced root development with brown spots on roots and coleoptile. Scouting should occur once seedlings begin to emerge and when patches become noticeable. Seedlings that have emerged should be inspected for any brown spots or pinching on their roots. If the disease is widespread, it may warrant reseeding and using a seed treatment. Root rots in later plant stages can cause whitening of the wheat head or whole plant. Digging up the plant to look at its roots is necessary to determine if the whiteness is caused by root rot.

Management

Using clean certified seed will help reduce the risk of disease. When using farm saved seed, it is recommended a seed treatment is used especially during high moisture environmental conditions. Note that fungicide seed treatments do not provide season-long protection. Avoiding seeding too deep and maintaining adequate soil fertility will help reduce disease occurrence by minimizing stress on germinating seedlings.

Common Diseases in Barley

Bacterial Leaf Streak

Xanthomonas translucens pv. *translucens*
Xanthomonas translucens pv. *undulosa*

Bacterial leaf streak (BLS) has been present for many years in Western Canada, but in recent years has become more widespread. The disease is caused by a bacterium, therefore, management strategies are limited for producers in season. BLS' host range includes cereal crops and grassy hosts. The disease impacts yield and grain quality and flourishes in moist conditions, with 15 to 30 C being optimal temperatures for spread. For information on BLS on wheat, go to the wheat disease section.

Disease Cycle

The bacterium can overwinter on perennial weeds, but the most common source of inoculum is infected seed sources. Infected seed sources lead to infected plants that, during periods of wet weather, can use wind and rain splash to rapidly spread BLS across a field. The infection moves its way up the plant affecting developing kernels. Weather events like hail favour disease spread as the bacterium can easily penetrate hosts through wound sites. It is important to note that bacterium generation time is short (less than one hour) versus fungal leaf diseases (7-14 days). This means BLS can spread at a rapid pace under the right moist conditions. The bacterium overwinters on plant debris and to a lesser extent, in the soil. Most transmission of the disease comes from infected seed sources.

Symptoms and Scouting

The disease initially appears as water-soaked lesions on leaves of the plant. These lesions start on green leaf material but later the lesion yellows as the disease develops. During moist conditions, bacterial ooze will form on these lesions and look like milky water droplets. Hold infected leaves up to sunlight and these lesions will appear translucent. As these symptoms move up the plant, spots and bacterial ooze can be noted on glumes. If BLS is suspected, send samples to a lab and have any seed sources tested.

Management

Most management options for BLS should be implemented before the growing season begins, and limited options are available. Clean seed sources are a critical step in the prevention and management of BLS. Test seed sources to avoid introducing the bacterium into new fields and areas. If BLS is introduced into fields, a crop rotation with breaks from susceptible host crops can help reduce the disease's impact. Fungicides will not work on BLS, as it is caused by a bacterium. Research is underway to identify potential host resistance or seed treatments.

Figure 4.2 Bacterial leaf streak in barley

Barley Yellow Dwarf

Barley yellow dwarf virus (BYDV) is a virus transmitted by aphids affecting barley, wheat, oats and over 100 other grass species. This virus affects crops on a global scale and is often seen in Western Canada. Potential yield loss from BYDV varies greatly depending on the time of infection. Early season infections can result in yield losses of up to 30 per cent, while later infections have minimal impacts. The spread of BYDV is dependent on infected aphid populations that are carried on winds coming from south of the province. Infection is favoured with cooler temperatures (18-20 C) and moist conditions.

Disease Cycle

In Western Canada, BYDV is reliant on several species of infected aphids being carried north to Western Canada by southern winds to cause infection. As these aphids find grassy hosts to feed on, they transmit the virus via 'honeydew' left on the plant after feeding. From here, the plant becomes infected with the virus and begins to infect other aphids feeding on it, allowing more aphids to become vectors and spread BYDV. Infections can occur anytime during the season and are dependent on aphid populations. In Western Canada, the only source of inoculum is aphid populations being blown in from the south as they do not survive the harsh winters. In warmer climatic conditions, aphids can overwinter in grasses and appear in the spring to spread the disease, or winter cereals can harbour the disease, acting as a green bridge. Overwintering aphid eggs and seeds from infected plants do not serve as sources of inoculum.

Symptoms and Scouting

After the initial infection from the aphid occurs, the virus begins to replicate itself in the plant and the first symptoms are visible within two to three weeks. These symptoms begin as yellowing or reddening at the leaf tips, progressing from the margins into the midrib of the leaf. As the plant continues to grow, its leaves may stiffen, and root growth is affected. If the infection occurs earlier in the season the plant can become stunted, have reduced foliage, and have sterile heads that may or may not emerge. Later season infection results in minimal symptoms. If infection occurs above 30 C, symptoms are unlikely to develop, but reduced vigor can still impact yields. Plants can be sent into a lab to determine the presence of the disease.

Management

Managing BYDV begins with seeding barley early to try to get the crop through its most susceptible stages before populations of infected aphids arrive. Certain varieties of cereal crops have more tolerance for BYDV than others, but no effective resistance exists. The level of infection in aphids will vary from year to year. Insecticide applications to control aphid populations are often not economical, due to the difficulty of detecting infected aphid populations early enough. Diversifying crop rotations can help to reduce inoculum sources that may overwinter in areas with milder winters. Manage volunteer wheat, barley, and oats to prevent them from becoming late-season hosts for aphids and viruses. Once symptoms are seen during the growing season, there is little that can be done to manage the virus.

Fusarium Head Blight

Common species found in Saskatchewan:
Fusarium graminearum (most aggressive)
F. avenaceum
F. poae
F. sporotrichioides
F. culmorum

Fusarium head blight (FHB) is a common disease in Saskatchewan affecting cereal crops. Major hosts of FHB include barley, spring wheat and durum wheat. The disease results in poor yield and the formation of fusarium damaged kernels (FDK). These lead to reductions in grade and end use quality, limiting producers' ability to sell infected grain. Of the different fusarium species, *F. graminearum* is the most aggressive and infection from it leads to the production of a mycotoxin called deoxynivalenol (DON). The presence of DON in barley grain causes end use issues for both malting and livestock feed. There is zero tolerance for DON in malting barley, while tolerance in feed is low, with livestock varying in sensitivity. Refer to Fusarium Head Blight under Common Diseases of Wheat for more details on this. Warm and moist conditions during flowering favour disease development.

Disease Cycle

Refer to Fusarium Head Blight under Common Diseases of Wheat for the full disease cycle.

High temperatures and humidity during flowering have a significant impact on disease development. Barley is most susceptible to FHB during the two weeks following heading, but infection can occur any time after heading. The pathogen overwinters on cereal stubble.

Symptoms and Scouting

FHB symptoms differ slightly between cereal crops. In barley, the first symptoms will be seen after heading when affected kernels on a head become tan in colour. Often unaffected spikelets on the head will remain green, while affected spikelets can be differentiated by their tan colour. Under humid conditions, white, pink or orange clusters can form on the base of a glume. FHB can be more difficult to identify in barley than in wheat because of long awns or hulled varieties. Infected spikelets result in FDK kernels that are thinner and smaller, but not much lighter than a healthy kernel. In wheat, FDK kernels are often much lighter than healthy ones, which makes it possible to adjust combine settings to blow them out the back of the combine. In barley, you are more likely to harvest FDK kernels during harvest. The earlier the infection occurs in the season, the more likely you are to see symptoms. If infection occurs later, it can result in kernels that do not have symptoms but do have high levels of DON.

Management

Many management strategies for FHB need to be used in tandem for the most effective control. Rotating crops away from susceptible hosts for one to two years will help to reduce inoculum overwintering in the field. Several 2-row barley varieties are on the market that have some resistance to FHB. Consult provincial seed guides for the latest varietal information. As the infection can be seed-borne, it is important to start the season with a clean seed source. Seed testing will help to detect any levels of FHB on grain sources, and this, paired with available seed treatment, will give the crop a good start. During the season, foliar fungicide applications can be used for suppression of FHB. Use the prairie-wide FHB risk map to get up-to-date information on current weather conditions and use available risk assessment tools to determine if a spray is warranted. Consult the provincial Guide to Crop Protection for the latest information on fungicides available.

Because *Fusarium* species have such a wide host range, including broadleaf and cereal crops, crop rotation may not be as effective for this pathogen compared to other pathogens. Seed treatments are available for most crops and can prevent infection during the seedling stage when infection can cause plant death.

Figure 4.3 Barley head with fusarium head blight

Net Blotch

Pyrenophora teres

Net blotch is a common foliar disease that mainly affects barley, with limited impact on other grassy species. The fungal pathogen shows up in two forms: **net form net blotch (NFNB)** and **spot form net blotch (SFNB)**. These forms differ in the symptoms they express on plants and where they occur. Spotted net blotch is more common in west-central Saskatchewan. Disease development is favoured by mild temperatures and wet conditions. A dense crop canopy with humid conditions is an ideal environment for the pathogen to spread. Yield loss varies depending on the level of infection and form of net blotch, with severe cases causing up to 40 per cent yield loss.

Disease Cycle

Net blotch overwinters on infected seed and crop residue. Infected seed sources will directly affect emerging seedlings, with infections worsened by cooler temperatures (10-15 C). High humidity and temperatures of 20 C encourage sporulation. Spores emerging from infected crop residue will spread to new hosts through wind and rain. During the growing season, spore production from newly infected plants can further spread the disease within the field. As the disease moves up the plant, developing kernels become infected.

Symptoms and Scouting

Net blotch affects the foliage and heads of barley crops. Both forms of net blotch start as light green or brown spots that begin to grow with time. Net form net blotch symptoms begin as small brown spots that begin to elongate and follow leaf veins in a longitudinal 'net-like' pattern that can be several centimetres in length. Spot form net blotch symptoms begin as small brown spots that grow into an oval shape about 0.5 to 0.3 cm in size that will not elongate (often mistaken for spot blotch). Both types of net blotch can have a chlorotic yellow area surrounding the lesion. If the infection moves into developing kernels, it can reduce germination and create inoculum that is carried over in the seed. If suspected, a leaf sample can be sent away to confirm the presence of the disease. Seed tests can determine if inoculum is present and assess any impacts on germination.

Management

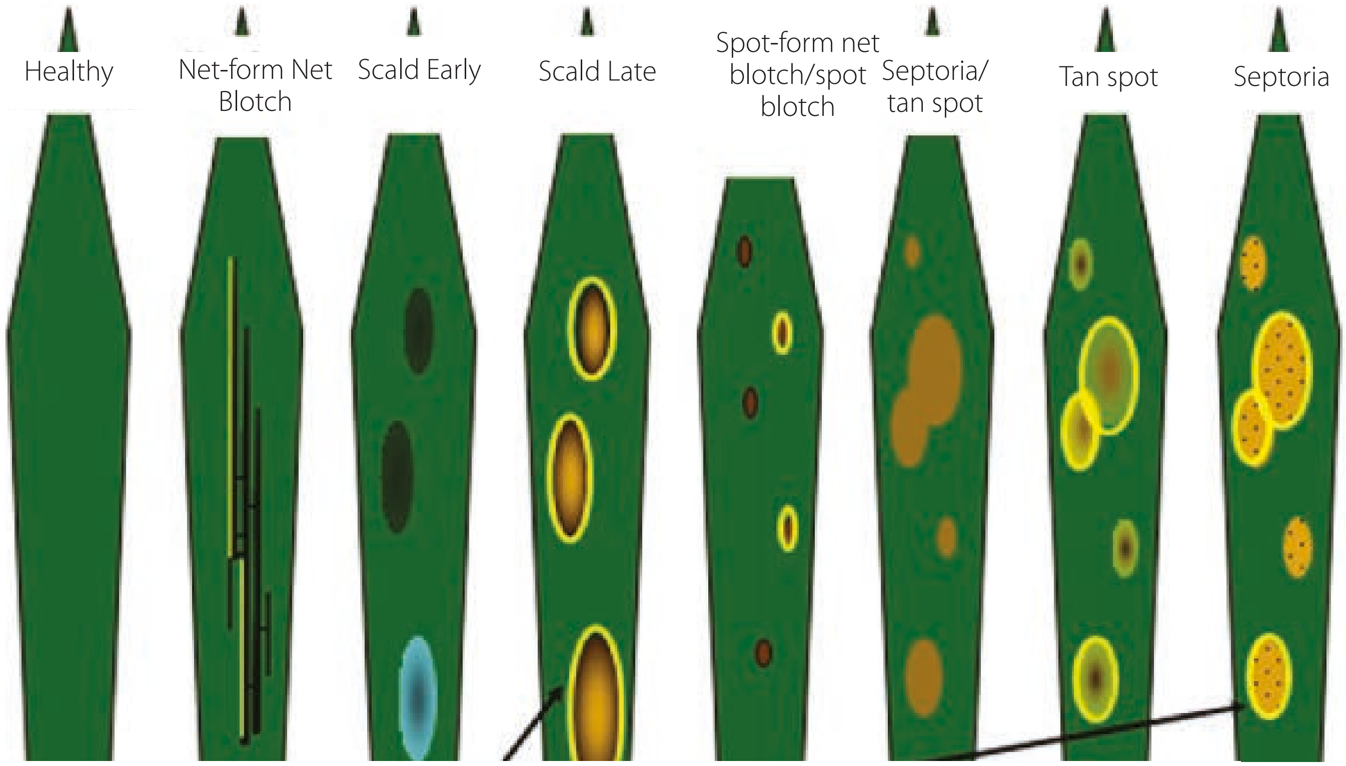
Crop rotations allow for a break between susceptible barley crops and provide time for inoculum on crop residue to break down. If a field is infected, a minimum two-year break from a host crop should be implemented. Resistant barley cultivars are available to producers. Resistance and other variety characteristics can be reviewed in the provincial seed guide. Producers can implement seed testing to ensure that their seed sources are free from the pathogen. Seed sources from infected fields can have exceedingly high infection levels, so it is important to avoid bringing inoculum to the field via a contaminated seed source. Seed treatments can be used to protect the plant earlier in the season but will not prevent infection later in the season. Foliar fungicides can be applied to control net blotch in season. Check provincial guides for up-to-date fungicide information and economic thresholds.

Figure 4.4 Net form net blotch on barley

Figure 4.5 Spot form net blotch on barley leaves

Figure 4.6 Spot form net blotch on barley

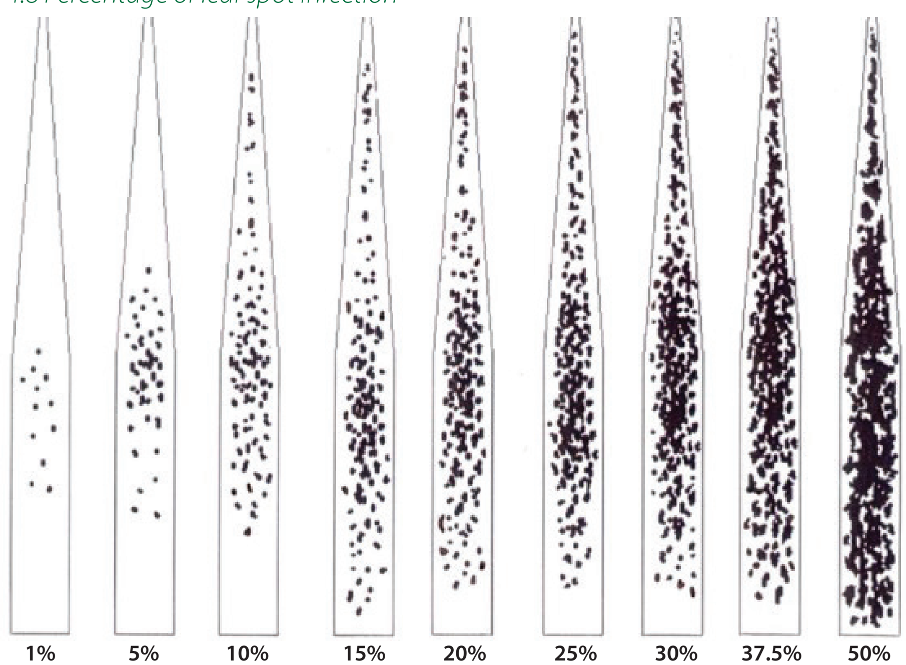
Figure 4.7 Typical symptoms of cereal leaf spot diseases



Note the development of chlorosis (yellowing) around well-developed symptoms.

Courtesy of: AAFC

Figure 4.8 Percentage of leaf spot infection



Courtesy of: AAFC

Scald

Rhynchosporium secalis

Scald is a fungal disease of barley common on the prairies. The fungal disease typically impacts barley, but rye and wild grass species can also act as hosts. Cooler and wet environmental conditions favour disease development. Yield loss varies depending on the severity of infection, but as scald is a polycyclic disease it can build up inoculum and spread quickly throughout a field in the right conditions. Yield loss typically is due to loss of foliage leading to reduced plant growth and grain fill.

Disease Cycle

Crop residue is the primary source of inoculum in the spring. Infection occurs when spores produced from crop residue spread to new plants, primarily by rain splash. From here the spores will infect new plant material. As this is a polycyclic disease, it can continue to repeat the lifecycle every 14 days, moving rapidly through a crop. Environmental conditions have a significant impact on the pace of spread, favouring cooler temperatures (12-14 C) and moist conditions. Infection can occur at any crop stage. The pathogen can become seed-borne, but the primary source of infection is inoculum on crop residue.

Symptoms and Scouting

Initial symptoms begin on leaves and sheaths of the plant as oval-shaped, water-soaked, greyish-green lesions. As the disease progresses, these lesions begin to dry out and dark brown margins remain while the centre becomes bleached. This bleached area can become dry and brittle, eventually falling out. As the infection spreads on the plant, lesions can accumulate resulting in loss of the leaf.

Management

Crop rotation is a key management factor for scald in barley. A two-year break from susceptible host crops allows for infected crop residue to break down. Resistant varieties for scald are available but should be rotated often, as scald is genetically variable and new pathotypes can overcome resistance under tight rotations. Consult provincial seed guides for the latest information. Clean seed sources with good germination and vigor can be paired with seed treatments to provide early protection. Foliar fungicides can be applied preventatively to control scald in season based on disease risk. Check the Guide to Crop Protection for up-to-date fungicide information and economic thresholds.

Figure 4.9 Scald on barley leaves

Smut, Loose

Ustilago nuda (barley)
Ustilago tritici (wheat)

Loose smut is quite common in barley fields in Saskatchewan but average losses from the disease are quite low. The seed-borne fungal disease affects the head of the plant preventing seed from developing. Cool, moist weather conditions during flowering, along with 95 per cent relative humidity and 20 to 25 C temperatures favour the development of loose smut. Wheat and barley are the most commonly infected crops, with infection in durum being minimal due to it normally being grown in drier areas of the province. Infected grain is not downgraded nor affects quality for livestock or human use since spores of loose smut do not accumulate on the seed. However, infected seed with loose smut will affect the value of grain used as seed. The average loss is less than 1 per cent, but fields with 5-25 per cent of the plants infected are not uncommon.

Figure 4.10 Loose smut on barley

Disease Cycle

Spores of the loose smut fungus blow and land on healthy flowers and will germinate if the air is sufficiently humid and the temperature is between 16 and 22 C. Spores develop mycelium and penetrate the ovary, which results in mycelium establishing in the embryo. As the seed matures, the mycelium becomes dormant. The infected seed does not look different from healthy seed. Once the seed germinates, the mycelium starts to grow again and penetrates the plant tissues near the growing point. As the head begins to form, it is so thoroughly invaded by the fungus that a mass of spores develops inside the normal spikelets. The spores mature by heading time and are dispersed by wind and rain. Spores that land in the flowers of healthy plants complete the disease cycle.

Figure 4.11 Loose smut on barley head

Symptoms and Scouting

Symptoms appear from heading to maturity and can also be present on tillers that may be stunted. Infected heads are black and filled with dusty spores and tend to emerge shortly before healthy green ones. As the crop matures, the spores are blown away or washed off leaving a bare rachis. Often there will be traces of dark spores and some greyish remnants of glumes or awns on the bare rachis if the tissue has not completely broken down.

Management

Using a resistant variety and disease-free seed is the best way to prevent infection. A systemic seed treatment can also help prevent infection.

Spot Blotch

Cochliobolus sativus

Spot blotch is a common foliar disease in wheat and barley, not only on the prairies but on a global level. The fungus that causes the disease (*C. sativus)* is also responsible for common root rot in cereals earlier in the season. Primary hosts of the pathogen are wheat and barley, but it also affects other cereal crops and grass species. Spot blotch occurrence is very dependent on environmental factors, needing warm temperatures (18 to 32 C) and periods of high humidity to sustain leaf wetness for 12 to 18 hours in order for infection to occur. Yield loss can vary greatly depending on variety and environmental conditions. If an infection is severe and moves up to the head of the plant, it can result in black point or smudge on kernels, a common downgrading factor in cereals. Refer to the Seedling Blight, Common Root Rot, Crown Rot and Foot Rot of cereals section for more information on *Cochliobolus sativus*.

Disease Cycle

Inoculum found on seed sources or in the soil leads to the infection of seedlings, resulting in seedling blight. In the spring, spores produced from infected crop residue are spread to the new crop by wind and rain. They begin to infect lower leaves of the crop. In warm temperatures and during prolonged periods of leaf wetness, spores from infected lower leaves will spread the disease further up the plant and to other plants in the field. As the disease moves up the plant, developing kernels become infected. Spot blotch is polycyclic, which can result in the rapid spread of the disease in the right conditions. A polycyclic disease can complete its disease cycle repeatedly in the growing season and infection stage can vary by plant or field area. The fungal pathogen overwinters on crop residue and in seed. It can remain in the soil for many years due to its thick-walled resting spore.

Symptoms and Scouting

Signs of infection are first visible on lower leaves as small brown oval spots. These spots are uniformly dark brown with a distinct margin, often surrounded by a halo of yellowed tissue and can grow in size. As the infection moves up the plant, symptoms can be found on new leaves, sheaths, stalk and heads. Severe infections on the stalk can result in 'neck break'. Infection on developing kernels can result in black point/smudge and result in downgrading. Samples of the plant can be sent to a lab to confirm a diagnosis.

Management

Since the disease overwinters on crop residue, implementing rotations that allow for a break between susceptible crops and time for residue to break down is beneficial. If a field is infected, a minimum two-year break from a host crop should be implemented. Resistant barley varieties are available to producers and can be reviewed in the provincial seed guide. Producers can test seed to ensure that their seed sources are free from the pathogen. Seed sources from infected fields can have very high infection levels, so it is important to avoid introducing the disease to a new field through contaminated seed sources. Seed treatments can be used to protect the plant earlier in the season but will not prevent infection later in the season. Foliar fungicides can be applied to control spot blotch in season. Check provincial guides for up-to-date fungicide information.

Figure 4.12 Spot blotch on barley leaf

Take-All

Gaeunmannomyces graminis

Although barley is a host of Take-all, the fungal disease rarely impacts yields for the crop. Refer to Take-All under Common Diseases of Wheat.

Disease Cycle

Refer to Take-All under Common Diseases of Wheat.

Symptoms and Scouting

Affected plants will have premature ripening that results in white heads and stunting. The disease rots the roots of the plants and turns them black, making it easy to pull affected plants from the soil. Tillering can also be reduced by the disease.

Management

If a field has a history of take-all, a crop rotation with a break from host crops will help to reduce disease inoculum. Seed treatments are available that can help protect emerging seedlings in the spring. Consult the provincial Guide to Crop Protection for the latest information on available seed treatments.

Common Diseases in Corn

Gibberella Stalk/Gibberella Ear Rot

Fusarium graminearum

Gibberella stalk rot and gibberella ear rot are both caused by the fungal pathogen *Fusarium graminearum*. Corn with gibberella stalk rot will not produce full ears and may lodge because of a weak stalk. The disease becomes worse when the crop is under almost any kind of stress. Gibberella ear rot results in yield loss from disease-infected ears that contain hazardous mycotoxins that livestock cannot consume. The same pathogen for gibberella ear rot infects wheat and causes fusarium head blight and can cause root rot in a wide range of broadleaf and cereal crops.

Disease Cycle

Refer to Fusarium Head Blight under Common Diseases of Wheat.

Infection of gibberella stalk rot takes place through roots or wounds in the stalk.

Infection of gibberella ear rot takes place through silks or through wounds in the cob from insects or birds.

Symptoms and Scouting

Source: South Dakota State University Extension

Gibberella stalk rot will produce wilted plants and leaves will change from a light to dull green colour. A tan to dark discolouration of the lower internodes and a pink to reddish discolouration within the stem will be noticeable. Fruiting bodies called perithecia will develop on the stalk surface. The lower stalk will become dry and the tissue will shred and disintegrate. Plants will lodge when the infection is severe. Start scouting for gibberella stalk rot after pollination. When infected stalks are pinched, they easily compress or are crushed.

Gibberella ear rot will cause ears to become spongy and husks will adhere tightly to the kernels. Pink to reddish mould grows down the ear, often originating at the ear tip. Symptoms of gibberella ear rot don't appear until after silking. Before harvesting corn, inspect your field for ear rots and stalk rots. Ear rots can lower grain quality, while stalk rots can lead to lodging, making harvest difficult. Ears touching the soil may also develop rots. Scouting for these issues is important for timely harvesting decisions.

Management

Since the pathogen also infects cereals like wheat, corn should not be put in a rotation with other cereals. Use hybrid varieties that show higher tolerance and control volunteer plants and weeds to reduce inoculum levels in the soil.

Figure 4.13 Gibberella ear rot

Courtesy of: Dr. White, Professor Emeritus at the U of Illinois

Figure 4.14 Slicing open the stalk to look for orange or red colouration is a necessity

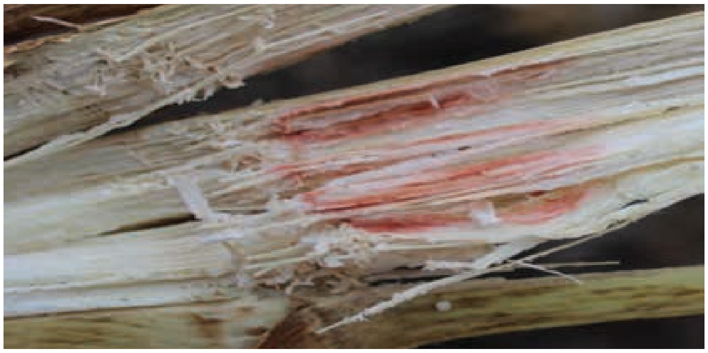


Figure 4.15 Infected stalks will snap at the nodes causing lodging

Figure 4.16 Perithecia (fruiting bodies) can be seen on the stalk and can be scraped off with a fingernail

Goss's Bacterial Wilt and Leaf Blight of Corn (Goss's Wilt)

Clavibacter michiganensis ssp. *nebraskensis*

Source: University of Minnesota Extension

Goss's wilt is a corn disease caused by bacteria. This disease has been identified in corn grown in Saskatchewan, but it is not widespread. Grain sorghum, sudan grass and several foxtail species are also hosts for this disease. In Minnesota, this disease can cause over 30 per cent yield loss when susceptible varieties are grown. Warm conditions favour disease development.

Disease Cycle

Goss's wilt usually infects leaves that have been injured. Insect feeding, hail, sandblasting, rain, wind, and strong storms are examples of possible causes of leaf injury. After infection, this disease spreads in the plant and can spread from one plant to another. Temperatures above 27 C favour disease development. The pathogen overwinters on infected crop residues. Fields with high levels of infection in crop residue, which may occur with short corn rotations, will have the highest disease severity. Seed transmission at very low levels is also possible.

Symptoms and Scouting

Disease symptoms first appear as water-soaked streaking on infected leaves. Later on, the leaf may have shiny exudate on it and the lesions will develop a long, greyish, wavy pattern following leaf veins. Dark specks, sometimes called freckles, may be present within the lesion. The freckles and shiny exudate are distinct symptoms of Goss's wilt. The lesions may have sticky exudates which will make the lesions appear shiny when dry. After silking, symptoms are the most visible and their severity increases.

Management

Extended crop rotations will be beneficial in reducing the risk of Goss's wilt. Fungicides are not effective at managing bacterial diseases.

Figure 4.17 Dark specks from goss's wilt

Figure 4.18 Water soaked streaking from goss's wilt

Smuts, Common and Head

Ustilago zeae - Common Smut
Sporisorium holci - Head Smut

Common and head smut are relatively destructive diseases in North America where corn is commonly grown. Both diseases are caused by fungal pathogens and infect both grain and sweet corn. Due to lower corn acres in Saskatchewan these diseases are highly sporadic compared to areas with higher concentrations of corn and shorter crop rotations. Common smut affects all parts of the plant while head smut infects young seedlings and spreads throughout the plant and will become noticeable only once ears and tassels have formed. These diseases prefer hotter drier weather. Temperatures of 26-34 C favour common smut while head smut prefers 21-28 C. These diseases, while common where corn is grown, do not typically result in significant economic losses. However, head smut is more destructive due to it infecting the plant at a young stage and growing throughout the plant.

Figure 4.19 Corn smut gall

Figure 4.20 Corn smut gall

Disease Cycle

Teliospores of both common and head smut overwinters in the soil or on crop residue. These spores are viable for several years and are spread by wind and rain. Initial infection can develop where wounds have occurred from insect feeding, hail, wind, or other causes. Gall development is most favourable on leaves, stalks, tassels, silks, and ears during warm, moist conditions. Drought or wet environmental conditions during or after pollination increase the potential for kernel infection because non-fertilized ovules and attached silks are susceptible to infection for an extended period. In the case of common smut, each point of infection is a separate event because the fungus is not systemic within the corn plant. Any contaminated plant material is still palatable to livestock and the spores will survive the journey through their digestive system.

Symptoms and Scouting

Common smut affects all parts of the plant above ground, especially young and actively growing tissue. Large galls will develop on stalks and eventually, the cells within these galls begin to die and the mycelium is converted into a dark mass of spores covered by a greyish-blue membrane. Galls can also form on leaves, but these are typically very small and contain few spores. Young plants with large galls will be stunted, barren, and produce smaller ears. These plants typically don't survive severe infections. Infection of ears typically results from spores germinating on the silks which leads to the infection growing down to the kernels.

Head smut infects young seedlings and grows throughout the whole plant during the rest of the growing season. Visual symptoms will not be noticeable until ears and tassels have formed. Infected ears will be smaller, rounded, absent of silks and may have galls. These galls will be covered with a thin tissue that will break open and expose a black spore mass and remains of shriveled plant tissue. Tassels may be transformed into a mass of sooty branches resembling loose smut on wheat.

Management

Plants infected with common or head smut and have visible galls should be destroyed to lower the chance of secondary infection. A long crop rotation will help reduce disease severity in the following years when corn is grown. However, spores can survive several years in the soil. Overall, areas of high infection should be avoided for several years to allow for the inoculum in the soil to break down. Picking a variety with improved resistance will help reduce the occurrence and severity of the disease. Since the spores are not commonly found on the seed coat, fungicidal seed treatments have a minimal effect. Systemic fungicide seed treatments may be helpful for head smut, especially if growing in an area where the disease has been present for multiple growing seasons. It is important to maintain nutrient levels in the soil. Fluctuations both high and low are conducive to common and head smut developing. Reducing physical damage from equipment as well as herbicide and fertilizer injury will help reduce infection.

Bacterial Blight

Pseudomonas syringae pv. *coronafaciens* - Halo Blight
Pseudomonas syringae pv. *striafaciens* - Stripe Blight

Two bacterial diseases infect the leaves of oats in the Canadian Prairies, halo blight and stripe blight. These two diseases are not overly damaging but in cases of severe infection, young seedlings can die. On older plants, the sheaths, panicles and leaves can be attacked, and heavily affected plant parts will wither and die. Humid wet weather is required for the disease to develop. The symptoms, disease cycle and control methods are nearly identical between these two blights. They are commonly mistaken for one another and are generally referred to as bacterial blight.

Disease Cycle

Both bacterial pathogens are seed-borne and overwinter on contaminated seed or crop residue. Infection begins with bacteria on the seed surface and then spreads from leaf to leaf and plant to plant. Infection can spread quickly during moist summer conditions, but warm, dry weather will halt the development of bacterial blight and new plant growth will be mostly free of symptoms. Infection that occurs during the growing season will occur through natural openings on the leaf surface such as stomata or through wounds from various kinds of injuries.

Symptoms and Scouting

Between the two diseases, there are slight differences in the symptoms you will see in the field. Halo blight produces light green, oval spots with water-soaked centres and dark margins. Pale green halos can surround these spots. Eventually, these spots and the halo will turn brown. Stripe blight will produce spots that do not have a pale green halo and will elongate into stripes between veins. In both diseases, heavily infected leaves will turn brown, wither and die; at this stage they are nearly impossible to differentiate between.

Management

Clean seed should always be used to ensure the lowest risk of disease. After years of high incidence of infection, a non-host crop should be planted to allow any infected plant residue more time to break down. Oat cultivars are not evaluated for their resistance against these diseases so there are no recommendations on varieties that would provide better tolerance or resistance. Producers should focus on using clean seed and having a longer rotation to reduce their risk.

Rust, Crown (Leaf Rust)

Puccinia coronata f.sp *avenae*

Crown rust is not typically a problem across Saskatchewan. Problem areas are normally found in the southeast and east-central regions of the province. These areas are at risk due to their proximity to Manitoba and are in the path of fungal spores coming north from the United States. Crown rust specifically targets cultivated oat, wild oat and a few other wild grasses but will not infect wheat, barley or rye. Mild to warm temperatures of 20-25 C with sunny days and mild nights of 15-20 C combined with adequate moisture to produce dew, result in spore germination and disease development. Yield losses can range from 10 to 40 per cent or higher while using resistant varieties. Susceptible varieties can see losses exceeding 80 per cent. Heavy infection will result in loss of grain quality.

Figure 4.21 Crown rust on buckthorn

Figure 4.22 Advanced crown rust on oat

Figure 4.23 Crown rust teliospores on oat

Figure 4.24 Crown rust on oat leaf

Disease Cycle

The disease cycle starts with resting spores called teliospores, which germinate early in the spring to produce spores called basidiospores. These spores are carried by wind and must infect an alternate plant, the buckthorn bush, to complete the life cycle. Buckthorn is a tree-like shrub that produces berries that birds feed on, helping spread the seeds around. The basidospores infection on buckthorn results in the production of aeciospores. The aeciospores are spread by wind and infect oats to cause crown rust. Spores that are produced on oats are called uredospores. These become a secondary source of inoculum. Infections on oats later turn into black teliospores, the overwintering spores for the crown rust pathogen. The crown rust pathogen can also infect a few wild grasses. Buckthorn is considered as a noxious weed in Saskatchewan and efforts have been made to eradicate it making the blowing in of spores the larger source of inoculum.

Symptoms and Scouting

Crown rust can develop on oats at any growth stage provided there is inoculum and the weather is conducive for infection to take place. Crown rust symptoms start as chlorotic spots on the lower leaves. As symptoms advance, these spots develop into raised reddish-orange pustules. These pustules are loaded with microscopic spores called uredospores. These are blown by wind or spread by rain splash to cause secondary infections throughout the field. Pustules can develop on leaf sheaths, stems and panicles but the pustules on leaves are the most damaging. Depending on the time of infection, infected plants can be stunted and have poor drought tolerance. As the oats mature, the crown rust pustules turn black, an indication of forming resting spores called teliospores. Scouting should occur around the emergence of the flag leaf through to head emergence to determine the need for a fungicide. Once the flag leaf is covered with pustules it is too late to apply fungicide.

Management

Planting crown rust-resistant/tolerant oat varieties will help reduce losses even during heavy infection years. Applying a well-timed fungicide to a susceptible/moderately susceptible variety can provide protection and limit losses. Scout oat fields at flag leaf emergence through head emergence to determine the need for a fungicide. Fungicide application decisions should also be based on weather forecasts and the growth stage. Where possible, plant oats early to escape infection. The later the oats are infected (after heading), the less yield loss will occur.

Bacterial Leaf Streak (BLS)/ Black Chaff

Xanthomonas translucens pv. *undulosa*

Bacterial leaf streak (BLS) is not a new disease and was first reported in the 1920s, but was never considered economically damaging to crops until recently. The disease is becoming more prevalent across Saskatchewan and the western prairies due to favourable weather conditions and increased awareness from researchers and producers. The bacterial pathogen that causes this disease prefers wet humid conditions and can infect wheat, barley, oats, triticale and perennial grasses. The disease is mainly seed-borne but research suggests it can also overwinter on winter cereals. Severe infections can result in yield losses of up to 50 per cent.

Disease Cycle

Bacterial leaf streak has multiple disease cycles in a single growing season (polycyclic). The bacteria can overwinter on crop residue, but BLS is primarily a seed-borne disease. The pathogen remains dormant in the seed until it is introduced to moisture. Moisture and adequate temperatures of 15-30 C are required for these cells to grow and multiply. Due to this, BLS thrives in areas with warm days, cool nights and an abundance of moisture. Rain splashing, wind, irrigation and mechanical field activities can help facilitate the spread of the disease within a field or to adjacent fields. Once present in a field, the bacteria can enter plants through natural openings such as stomata or wounds caused by a multitude of sources. BLS lesions begin to expand and lengthen and are typically found bordered by leaf veins. This causes the spots to elongate and form streaks and gives the disease its name.

Symptoms and Scouting

Bacterial leaf streak can be very difficult to properly diagnose within a field since it displays several symptoms that are easily confused for fungal leaf spot disease in Western Canada. In the early stage of development, lesions appear as small, oval, light green, water-soaked spots/streaks and could have a translucent appearance. Under wet conditions, these lesions will produce a milky white or yellowish ooze. This exudation of ooze does not always occur but can help differentiate BLS from fungal diseases as the ooze will be full of bacterial cells and not spores. Dried bacterial ooze will give lesions a glazed like appearance. Later in development, lesions begin to join and form irregular streaks as they destroy photosynthetic tissue. Symptoms typically start on the middle or apex of the leaf where moisture stays the longest. Heavy infection will lead to withering and death of leaves. If infection occurs early in the season there can be significant damage.

Bacterial black chaff, which is caused by the same pathogen as BLS, infects the heads of wheat and barley. Dark lines or strips will become noticeable on the glumes and awns. Awned varieties might have alternating bands of diseased and healthy bands of tissue. In severe infections these stripes join together and turn the glumes completely black giving the name "black chaff". These heavily infected glumes will produce an ooze giving a water-soaked appearance.

Scouting for both diseases can begin during in-crop herbicide application timing through to the start of crop senescence. Special attention should be given to scouting after the occurrence of severe weather events such as strong winds, wind-driven rain, hail, heavy rain and thunderstorms.

Management

Producers should use clean seed and take advantage of seed testing labs to ensure the seed they might be keeping on farm is free of the bacterial pathogen. Crop rotations that are more than two years away from a cereal crop can help lower the risk of the disease by reducing the existing inoculum. On irrigated acres, special considerations must be made to avoid creating wet humid conditions. Irrigate in the evening when the canopy is already wet, allow the canopy to dry completely between irrigation events and only irrigate when essential.

Figure 4.25 Bacterial leaf streak (BLS) was frequently reported from Saskatchewan in 2022 growing season. The disease causes lesions that ultimately enlarge and take on a brownish appearance as they dry.

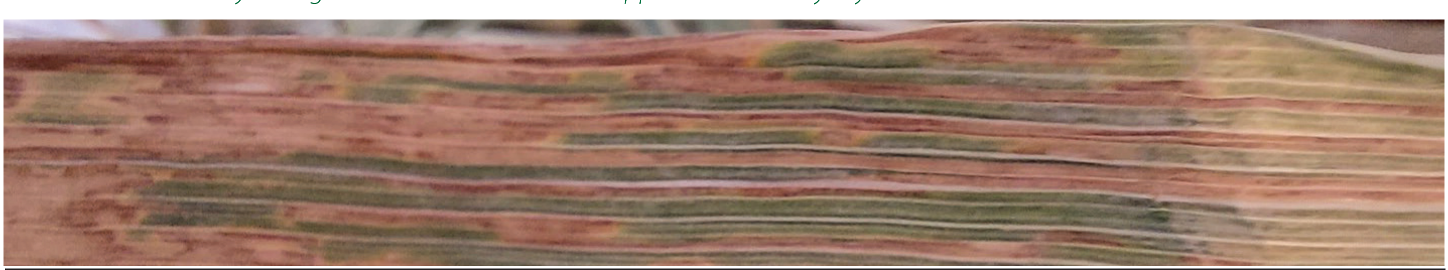
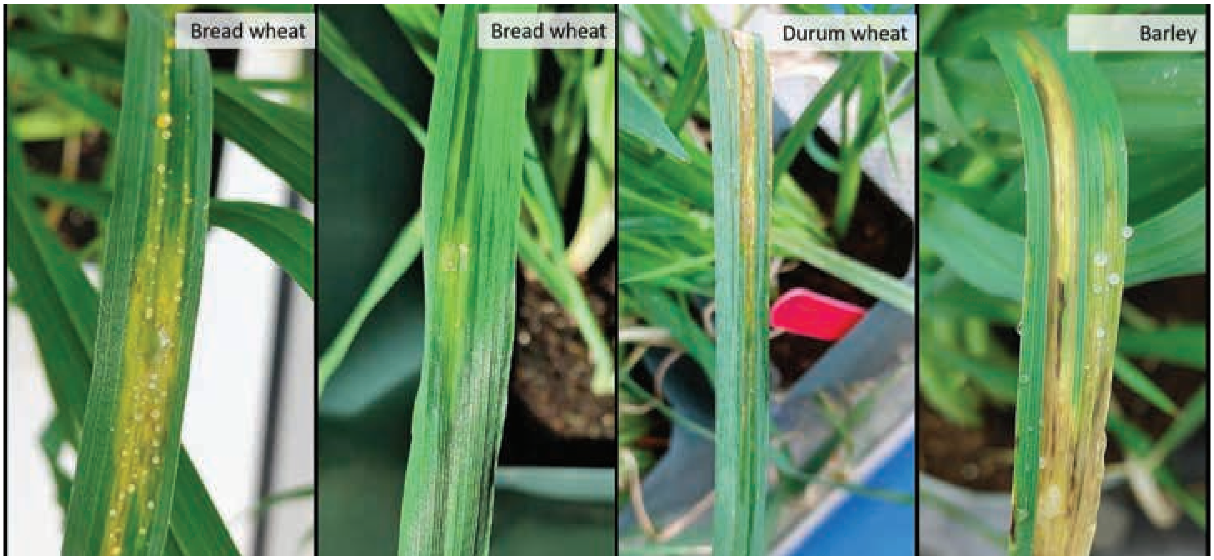


Figure 4.26 Oozing masses of bacterial cells on various cereals



Courtesy of: University of Saskatchewan

Figure 4.27 Black chaff in wheat

Common Bunt

Tilletia spp.
T. caries
T. foetida

Common bunt is typically found in wheat, but can also infect rye, triticale and several other grasses. The fungal disease is widespread, and it was once one of the most destructive diseases of wheat in North America before control measures were created and implemented. Historically, the disease was associated with winter wheat more than spring since winter wheat had less resistance and the disease favours cooling temperatures associated with fall seeding. The disease caused "bunt balls" which replace kernels of infected heads and contain the spores of the pathogen. Yield losses are equivalent to the percentage of infected tillers, but quality losses can be more severe. Grain infected by bunt even at low levels will have pungent, fishy odor causing them to be downgraded at the elevator or outright turned away. Bunted grain will contaminate the clean grain and grain buyers won't take the risk. Bunted grain is also very difficult to offload as livestock feed. Thankfully seed treatments are effective, and resistant varieties have eliminated the risk of bunt unless these control methods are not used.

Disease Cycle

Teliospores are released from the bunt balls during harvest and adhere to the surface of healthy grain or are carried by the wind to other parts of the field or adjacent wheat fields. These spores are capable of surviving in the soil for a year and are an important source of infection for winter wheat which allows the pathogen to overwinter. These teliospores germinate in response to moisture and infect the seedling through the coleoptile before the seedling emerges. Low soil temperatures of 5- 15 C favour spore germination and infection. Once inside, the pathogen overtakes the growing point of the developing plant and passively moves up the shoot. When head development begins, young kernel tissue is rapidly replaced with millions of teliospores. The only structure of the kernel that remains is the outer layer which forms the exterior of the bunt ball.

Symptoms and Scouting

Bunt is not noticeable in the standing crop until the crop is almost completely mature. Infected plants may be moderately stunted and remain green longer than healthy plants. The kernels of infected plants can be replaced by bunt balls or the heads can be completely or partially diseased with normal kernels and bunt balls on the same head. Bunt balls can resemble wheat kernels but are more spherical. They are blueish green at first but change to a grey brown at maturity, when they are most noticeable, especially after a rain. The covering of the bunt ball will remain intact until harvest when it is easily ruptured, releasing the mass of black teliospores. The fishy odor and cloud of teliospores is the first thing farmers notice when harvesting infected wheat.

Management

Bunt is easily controlled using bunt-free seed and crop rotation. Most classes of wheat have adequate resistance to bunt and should be used in combination with fungicidal seed treatments to achieve the most effective level of control. Seeding winter wheat early when soil temperatures are warmer or seeding spring wheat late when soil temperatures are warmer will reduce disease incidence.

Figure 4.28 Common bunt. The kernels are replaced with "bunt balls" containing the pathogen spores.

Ergot

Claviceps purpurea

Ergot produces distinctive hard black fungal bodies in place of kernels. These ergot bodies will vary in size and shape depending on the host crop. Ergot is more commonly seen during years with cool, wet conditions that promote the germination of spores leading to increased infection. Ergot is caused by the fungal pathogen *Claviceps purpurea*, which produces alkaloid toxins that are highly toxic to livestock and humans. Ergot can occur on a wide range of cereal crops and grasses. While it is most common in rye and triticale it can be quite prominent in spring wheat and durum if conditions are favourable. Conditions during the flowering period that prolong the pollination window or cause sterility increase the risk of disease. The conditions can range from cool, wet conditions to heat blasting. The yield loss to ergot is typically very low. The main concern comes from the downgrading of grain with dangerous levels of ergot bodies, resulting in large economic losses.

Disease Cycle

During harvest the sclerotia (ergot bodies) fall to the ground or are harvested with the grain. These bodies overwinter in the soil where they wait for favourable conditions in the spring and summer. Sclerotia on or close to the soil surface will begin to germinate and grow structures that release ascospores. These ascospores are blown by the wind and can land on open florets, penetrate the ovary and begin the disease cycle within the plant. This leads to the secretion of a sticky substance called "honey dew" on infected florets and eventually the appearance of ergot bodies. A secondary source of infection to healthy flowers on the cereal head is by rain-splashed or insect-borne conidia from the "honey dew" produced on infected florets. Ergot is often more severe in field margins due to the secondary spread from wild grasses.

Symptoms and Scouting

The most obvious symptom of ergot is the large, black, purplish sclerotia that replace the kernels of diseased heads. Infected heads can contain one or several sclerotia of various sizes. Early in the season before sclerotia are visible, early signs of infection can be observed upon close inspection of developing heads. After flowering has begun, a sticky liquid called honey dew can be found oozing from infected heads. It contains the asexual spores (conidia) which are spread by rain-splash or insects. The best time to scout for ergot is towards the end of the season during late flowering and ripening.

Management

Allow at least one year between susceptible crops especially rye. Use ergot-free pedigreed seed and take advantage of seed cleaning services if ergot is found in harvested grain. Low soil-available copper and boron, and some late-applied herbicides increase susceptibility. Cut grasses near fields before flowering to prevent grass-to-cereal spread. If ergot is severe only at field margins, harvest those areas separately to avoid contaminating all the grain. Seed cleaning removes most sclerotia. Use a fungicide for ergot suppression.

Figure 4.29 Ergot bodies (sclerotia) on triticale

Figure 4.30 Ergot body (sclerotia) on canaryseed

Figure 4.31 Ergot bodies (sclerotia) on wheat

Figure 4.32 Ergot body (sclerotia) on rye head

Fusarium Head Blight

Common species detected in SK:
Fusarium graminearnum
F. avenaceum
F. poae
F. sporotrichioides
F. culmorum

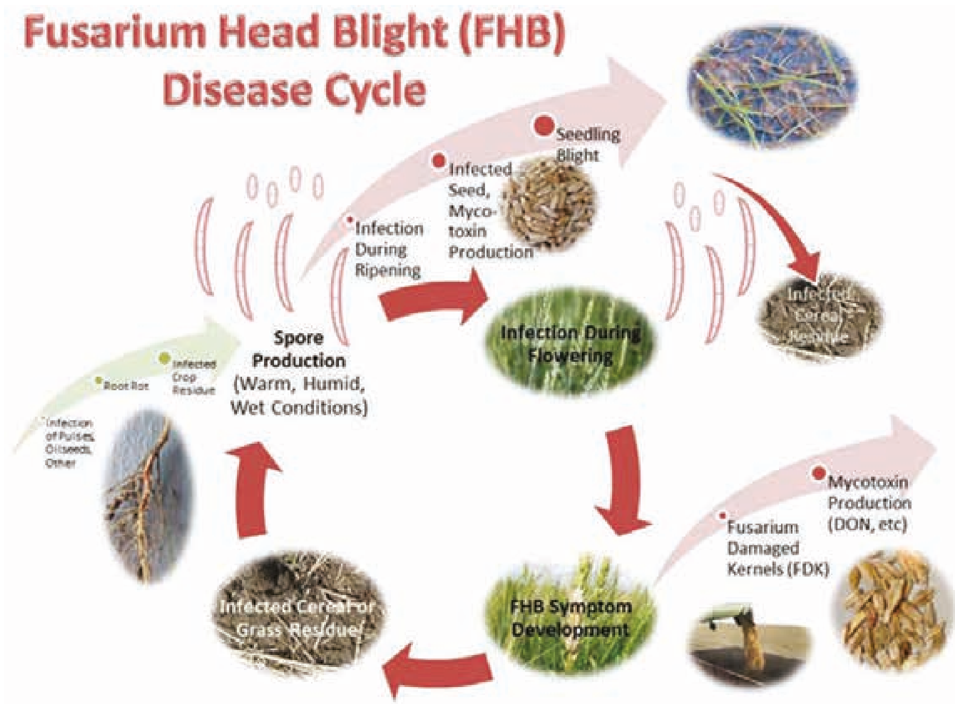
Fusarium head blight (FHB), also known as "scab", is a major economic disease of small grain crops like wheat and durum in Saskatchewan and Western Canada. It is most commonly caused by the fungal pathogen *Fusarium graminearum*. It can affect a large number of host crops including wheat, barley, oats, rye and corn as well as wild grasses across the prairies. Warm, humid wet conditions favour development and spread of FHB throughout grain crops. When the weather is dry and the humidity is low, risk of infection is lowered but still possible when inoculum levels are high. Yield loss can be greater than 50 per cent when infection is severe; however, the larger concern with FHB is the significant risk it poses in grain quality and food safety. The presence of mycotoxins (DON and VOM) can lead to discounts or rejections of entire loads of grain at points of sale.

Figure 4.33 FHB host tolerance from most tolerant (left) to least tolerant (right)

Disease Cycle

Residue from cereal crops grown in previous years are important sources of inoculum (spores) for initial infection. Infections by the FHB fungus take place during prolonged periods of warm, wet, and humid weather during the flowering growth stages in wheat. Two spore sources can infect and cause FHB. Sexual spores (ascospores) from residue are the primary source of inoculum and are wind and rain-dispersed to open flowers in small grain crops. Regardless of the source, spores land on the flowers and germinate; subsequently, the fungus grows into the developing kernel. Depending on the level of resistance in the variety of wheat, the fungus may continue to colonize other kernels in the head. If the environment remains conducive, the fungus continues to grow and sporulate resulting in pale pink or salmon-coloured masses (sporodochia). The fungus will cause kernels to shrivel and eventually be under-developed, or the FHB-fungus can colonize the outside of the kernel with no obvious symptoms yet result in the production of DON. FHB will overwinter on infected stubble residue and any infected kernels that fell to the ground during harvest.

Figure 4.34 FHB disease cycle



Courtesy of: Government of Alberta

Symptoms and Scouting

Symptoms of FHB on wheat spikes are most often visible after flower initiation and anthesis. Infected spikelets will prematurely die, becoming bleached (brown or straw-coloured) while non-infected spikelets remain green. Entire heads may be killed prematurely as the fungus colonizes tissues within the head. As FHB progresses, brown to gray areas may develop along the stem beneath the heads (peduncle). Seed will become shriveled, discoloured or may not develop at all. Signs of the fungus (sporodochia) develop when wet, humid conditions persist late in the growing season. Orange to salmon-pink spore masses may be first observed at the attachment of the small grain head to the stem, spikelet attachment to the rachis, or sometimes along the awns. Severely affected *Fusarium*-infected kernels will be lightweight, chalky, pink to red, and often blown out with chaff during harvest. However, "later" infections by the FHB pathogen may result in little to no symptom development of the kernels yet still have elevated concentrations of DON.

Management

There are no varieties currently available in Western Canada that are completely resistant to FHB; however, many moderately resistant wheat varieties are available and are the first line of defence for producers when lowering their losses to FHB. Longer rotations and proper residue management will increase infected residue decomposition and lower the level of inoculum in a field. Fungicides are also an option to manage FHB in wheat, however; the level of control is dependent on application timing, varietal resistance and conditions favouring an epidemic. Fungicides should be applied at the time of flowering to provide the best chance of protection to the wheat head.

Because *Fusarium* species have such a wide host range, including broadleaf and cereal crops, crop rotation may not be as effective for this pathogen compared to other pathogens. Seed treatments are available for most crops and can prevent infection during the seedling stage when infection can cause plant death.

Figure 4.35 How to determine if application is required for registered seed treatment

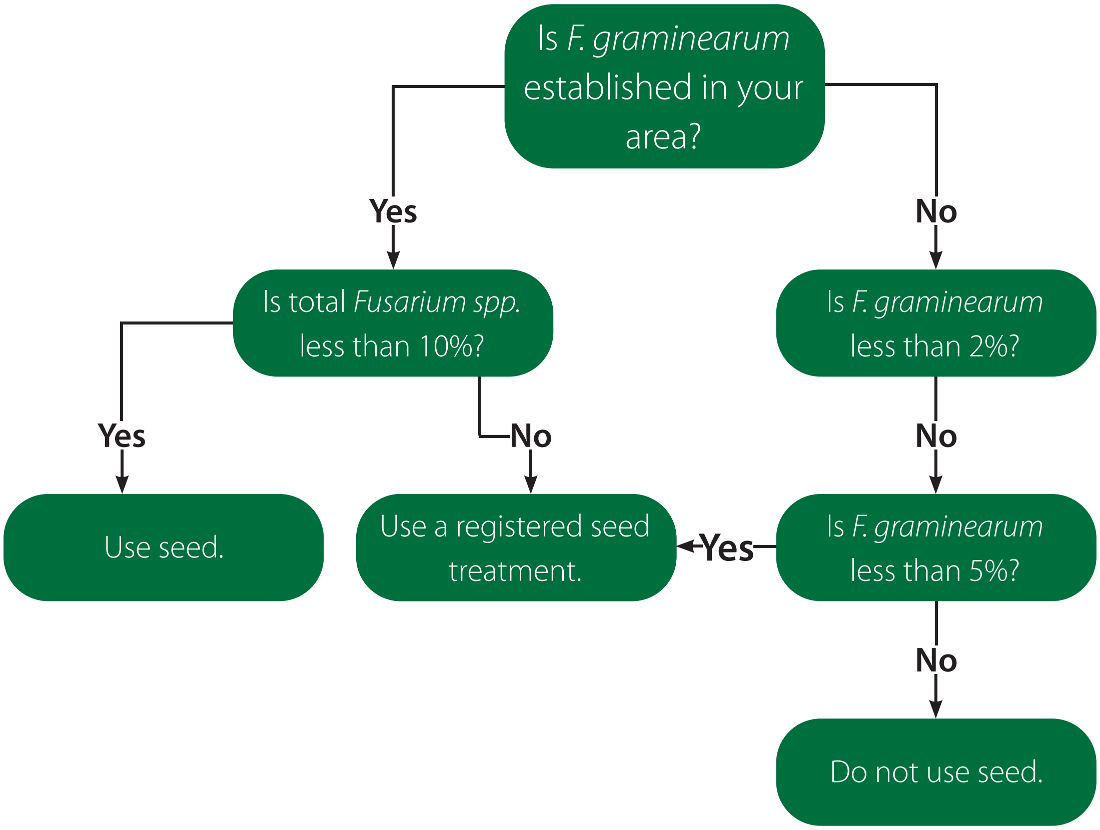


Table 4.1 Assessing fusarium head blight risk

Assessing Fusarium Head Blight Risk in Saskatchewan		**Lower Risk**	**Medium Risk**	**Higher Risk**
Step 1: Predict Pathogen Is *Fusarium* established here?	Has wheat produced in this field been downgraded due to fusarium damaged kernels? Has >5% *F. graminearum* been isolated from seed produced in this field? Has >10% other *Fusarium* species been isolated from seed produced in this field? Have any crops produced in this field experienced root rots due to *Fusarium* spp?	No No No No	By a grade >4 years ago >2 years ago >2 years ago	By >1 grade Within 4 years Within 2 years Within 2 years
Step 2: Stage Crop When will crop be susceptible?	Stage crop at least one week before expected flowering date. Use experience or estimate GDD from seeding date. Anticipate Day 0, when 75% of the heads on main stems to be fully emerged, to be 1-2 days before flowering. Also consider susceptibility of crop. Seeding Date +807 to 901 GDD C or 1484 to 1653 F = Expected Flowering Date	Even Crop, FHB Rating G or VG	Uneven Crop, More Tillers, FHB Rating F	Uneven Crop, Many Tillers, FHB Rating P or VP
Step 3: Watch the Weather Check FHB map	Select the FHB forecast map for the estimated head emergence date (Day 0), and determine risk for the area. At least 12 hours of precipitation or high humidity (above 80%) is required for *Fusarium* spore germination and infection, as well as favouring temperatures ranging from 16 to 30 C (*F. graminearum* optimum is 24 to 82 C)	Low	Moderate	High
Step 4: Crunch Numbers	Estimated Yield (unit/acre) x Estimated Yield Savings (%) x Selling Price ($/unit) MINUS the Fungicide Application Cost ($/acre) = Expected Net Return ($/acre)	Negative Net Return	Net Return $0	Positive Net Return
Step 5: Make a Decision	Note that foliar fungicides are registered for the suppression of FHB on wheat, rather than control. Flowering may be variable, but aim for when at least 75% of the heads on the main stems are fully emerged to 50% of the heads on main stems are in flower. Ensure adequate water volumes and spray coverage to get the most benefit from application.	Mostly Low Risk? Do Not Spray	Medium Risk? Pencil it in; reassess risk before spray day	Mostly High Risk? Likely to see a benefit from a FHB fungicide

GDD = Growing Degree Days VG = Very Good G = Good F = Fair P = Poor VP = Very Poor

Figure 4.36 Fungicide timing for FHB in wheat

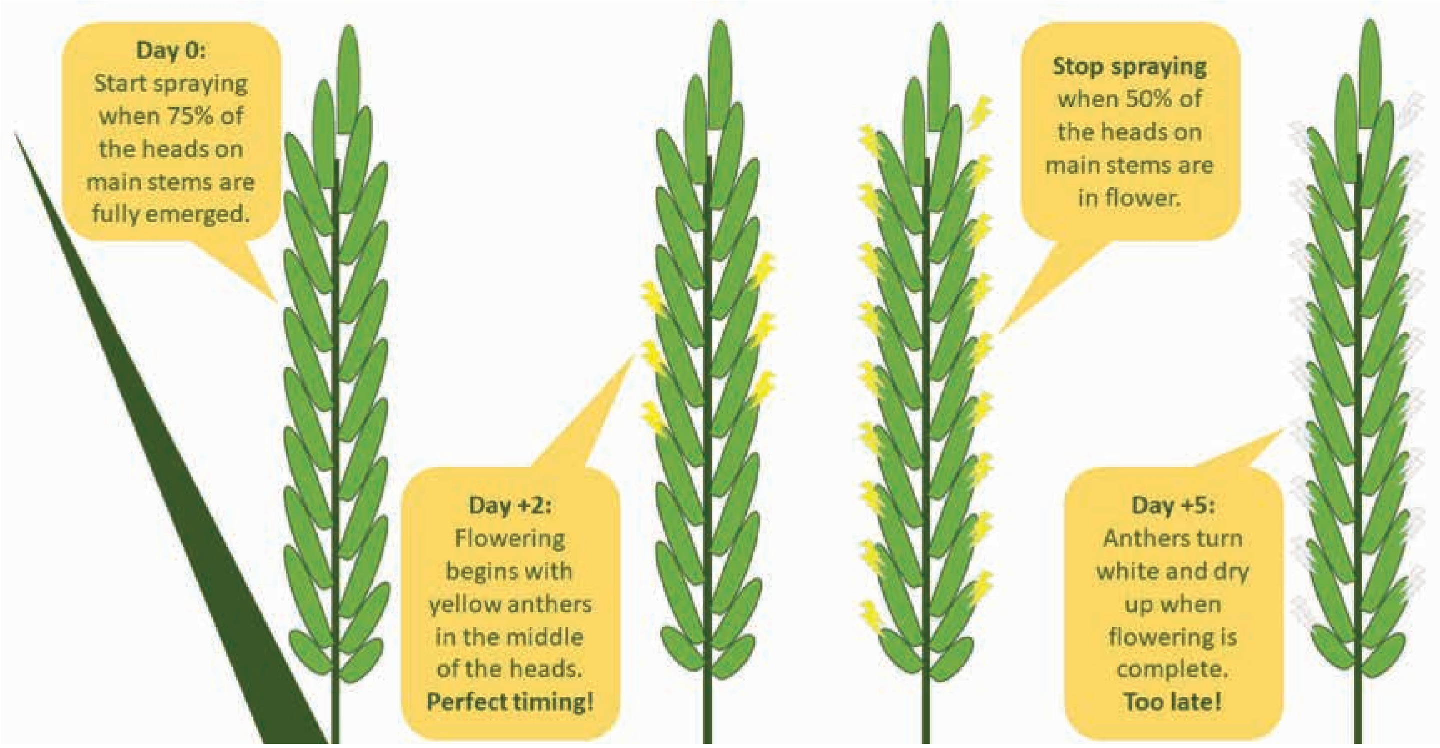


Figure 4.37 Fusarium and sooty mould on wheat head

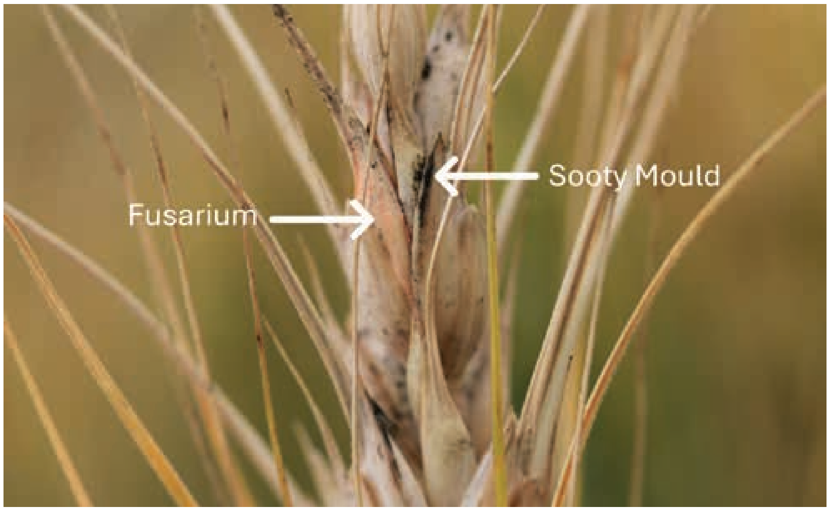


Figure 4.38 Fusarium head blight on wheat

Figure 4.39 Fusarium damaged kernels (FDK)

Figure 4.40 Fusarium head blight on wheat

Powdery Mildew

Blumeria graminis

Powdery mildew can affect wheat, barley and numerous grass species. This disease is most common during dry, cool seasons and has resulted in considerable damage in the past. Severe infections from this fungal pathogen can result in reduced kernel weight and yield loss. In Western Canada, localized infections occur almost every year and more widespread epidemics occur less frequently. Powdery mildew of wheat does not affect barley or oat, and powdery mildew of barley does not affect wheat or oat. Each form of mildew has similar symptoms to one another but is completely distinguished from the others by its ability to attack different host cultivars. While yield losses to powdery mildew are typically low, in severe infection years yield and quality losses have exceeded 40 per cent.

Disease Cycle

The pathogen overwinters on winter wheat crops. In the spring, ascospores and conidia are released and spread by the wind to growing spring wheat crops. New infections develop and produce a new batch of conidia that differ significantly from spores in many other fungi because they do not require moisture to germinate. The optimum condition for germination is 85-100 per cent relative humidity and moderate temperatures of 15-22 C.

Symptoms and Scouting

As the disease develops, small, greyish-white colonies of mycelium begin to form on the upper leaf surfaces. These colonies will grow in number and size until the whole plant is covered with a white, powdery mass. Infected leaves will eventually wither, shrivel and die. As the colonies complete their life cycles, they become grey and spotted with small black sexual fruiting bodies of the fungus. If the infection begins early and is severe, plants will be stunted and likely won't head out. When scouting fields, keep an eye out for the distinctive white masses that are indicative of powdery mildew.

Management

Seeding resistant cultivars is recommended, however finding information on which varieties are resistant may be difficult to obtain. Crop rotation is a good way of breaking up the disease cycle and lowering inoculum within a given field. Reducing crop residue will help lower the available inoculum and any volunteer wheat should be removed to stop it from being a source of infection for neighbouring wheat fields. Since winter wheat is a large source of overwintering inoculum, consideration must be made when seeding spring wheat adjacent to winter wheat fields. There are systemic and foliar fungicide products that can be used to provide control.

Figure 4.41 Powdery mildew on winter wheat

Rust, Leaf (Brown Rust)

Puccinia triticina

Leaf rust is a common fungal leaf disease in wheat and occurs in other cereals in Saskatchewan including barley and oats. Wheat varieties have varying levels of resistance to the disease. It's important to know that while a variety may be resistant, the virulent races of the pathogen can still attack and become more prevalent, eventually causing the variety to be reclassified as susceptible. This disease develops rapidly at moderate temperatures (11-22 C) when moisture is not a limiting factor. Leaf rust causes the most damage when appearing on the upper leaves prior to flowering causing potential early defoliation and limiting grain fill potential from damage to the flag leaf. Leaf rust can cause up to 25 per cent yield loss under favourable conditions.

Disease Cycle

Leaf rust overwinters in the southern states and Mexico. The disease moves north in the spring by producing urediniospores on wheat crops as they mature, with the southernmost wheat crops maturing first and the northernmost crops maturing last. The spores causing infection move north with the prevailing winds. In Western Canada the first leaf infections are usually seen in June and the disease reaches its peak in August. Black teliospores are the last stage in the disease cycle during the growing season.

Teliospores can overwinter in Canada and germinate to produce four basidiospores in the spring. These spores cannot infect wheat but can infect other plants in the genus Thalictrum (meadow rue). In Europe and Asia, plants belonging to this genus can form spores that infect wheat to produce urediniospores. The plants in this genus in North America are highly resistant to leaf rust and do not contribute to disease in wheat.

Symptoms and Scouting

Leaf rust lesions (pustules) are mostly found on the leaves but may also occur on the leaf sheath. They do not penetrate the stem tissue. The pustules are nearly round and much smaller than pustules of stem rust. They are yellowish-red to brown and may be so closely spaced on heavily rusted plants that the leaves appear orange-red. Rust in oats is more orange in colour. As plants ripen, the pustules darken due to the formation of thick-walled, black teliospores. Early scouting of leaf rust should be done in June and continue to its peak development in August.

Management

Resistant wheat varieties are available, but producers should check the current ratings of varieties since virulent races of the pathogen change rapidly. Early seeding may reduce disease severity, as losses are greatest on late-seeded crops. Most foliar fungicides are effective in controlling leaf rust.

Figure 4.42 Leaf rust on wheat

Figure 4.43 Leaf rust on wheat leaf

Rust, Stem (Black Stem Rust)

Puccinia graminis

Stem rust can be found throughout any region where wheat is commonly grown. Before the introduction of resistant varieties this disease was responsible for millions of dollars of losses. The disease is caused by a fungal pathogen whose spores overwinter in the southern states and blow north into wheat, barley and oat fields in Western Canada. There are several forms of rust that affect different cereals and grasses across the prairies. Wheat stem rust can affect wheat, durum and barley while stem rust of oats only attacks oats, wild oats and meadow fescue. Like most fungal diseases, humid conditions and temperatures around 20-25 C favour development. Stem rust was once the most devastating wheat disease across Western Canada, but resistant cultivars and the implementation of fungicides have since kept its incidence low in Saskatchewan.

Disease Cycle

There are two distinct reproductive cycles for the stem rust pathogen in North America. For Saskatchewan producers the asexual cycle is the most important, as this cycle is the repetitive infection of cereals by urediniospores. The cycle begins in the southern United States and northern Mexico where the urediniospores overwinter on winter cereals. Spores are produced and carried northward by the wind; this movement is known as the "Puccinia pathway". As the spores move north, they repeatedly infect susceptible winter and spring cereals. By mid to late June, these spores arrive in southern Saskatchewan and Manitoba, where they infect susceptible cereals and wild grasses. The severity of the disease is dependent on the amount, time of arrival, and virulent races of inoculum from the United States, susceptibility and growth stage of the crop and the weather conditions. The pathogen rarely overwinters in Western Canada due to the near eradication of the alternate host, the barberry bush. With no local inoculum present in the spring there is no possibility of disease early in the growing season. The sexual reproductive cycle for stem rust has multiple spore stages and requires both cereal and the alternate host. Thankfully the sexual stage is rarely seen in Saskatchewan as barberry was eradicated in the province in the early 20th century.

Symptoms and Scouting

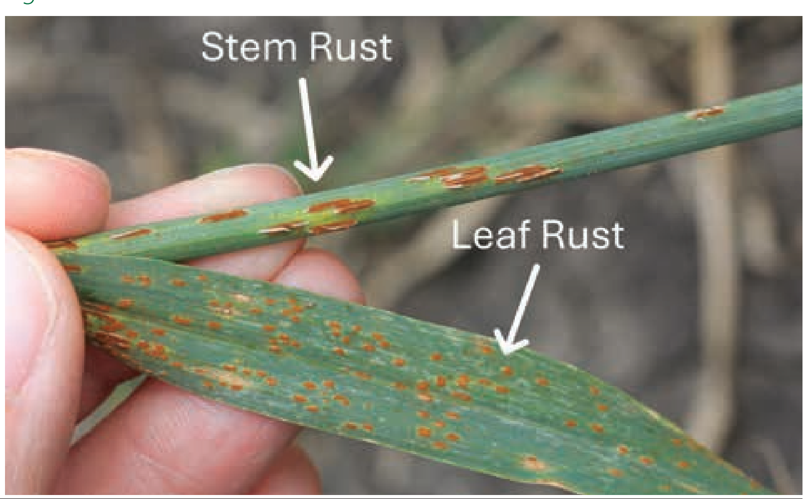
Deep red or brick-red pustules form on the stems of infected cereals and to a lesser extent on leaves. As the plant ripens, these putules will darken until they are almost black. This colour change is caused by the summer stage spores (urediniospores) changing into the overwintering spore stage (teliospores). This drastic colour change is often mistaken as a different disease altogether and is commonly referred to as "black stem rust". Since spores arrive from the south mid to late June, scouting should occur early July, especially if conditions have been warm and humid.

Management

The most effective control method is the destruction of the alternate host, barberry. Since this has been carried out and effectively eliminated the overwintering stage of the pathogen, resistant varieties of wheat, durum, barley and oats offer adequate control of the disease. If a susceptible variety is being seeded, it should be as early as possible to help to avoid the arrival of the spores later in the season. Foliar fungicides are effective, but their economic viability can depend on the severity of the disease and the timing.

Figure 4.44 Stem rust on wheat leaves and stems

Figure 4.45 Leaf and stem rust on wheat



Rust, Stripe (Yellow Rust)

Puccinia striiformis f. sp. *tritici*

Stripe rust, commonly referred to as yellow rust, is caused by the fungal pathogen *Puccinia striiformis* f. sp. *tritici*. It is one of the most common diseases in wheat across the wheat growing regions of the world and has caused significant economic loss in the past. The disease prefers temperatures from 9 – 12 C for optimal spore production, temperatures above 20 C will result in a suspension of spore development. The primary hosts of stripe rust are wheat, durum and ancient wheat cultivars such as emmer. Barley and rye can be affected but it is not common that epidemics are seen. Thankfully there is very strong varietal resistance in both common wheat and durum wheat grown in Saskatchewan, keeping the disease risk low. However, pathogen races are adapting and overcoming genetic resistance and are also adapting to changing weather conditions. Typically, yield losses can range from 10 to 90 per cent depending on variety resistance and environmental conditions.

Disease Cycle

The pathogen has no secondary host in Canada, unlike the pathogens that cause stem rust and leaf rust. The cycle begins when teliospores germinate and produce basidiospores which eventually develop into urediniospores. This pathogen can overwinter either as urediniospores or as dormant mycelium on native grasses or winter wheat crops in the Southern United States. In the summer, these urediniospores are spread by the wind from the south and are deposited across fields of spring wheat in Canada and the northern United States. During mild winters in certain parts of Canada, the pathogen can survive on winter wheat hosts; however, conditions are typically too cold in Saskatchewan. As the cycle comes to completion, teliospores are produced. Teliospores are not able to reinfect wheat plants and the cycle in Canada ends.

Symptoms and Scouting

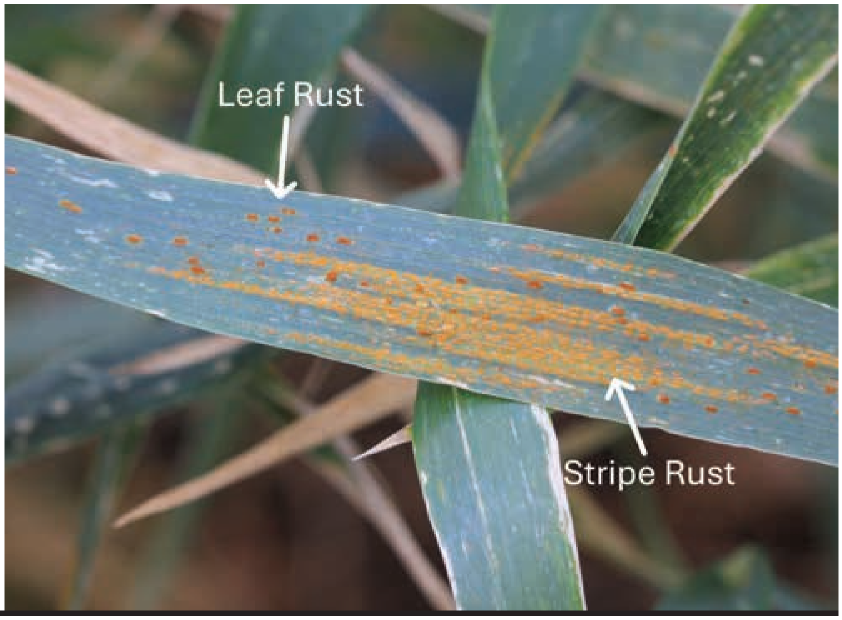
Stripe rust is characterized by long yellow-coloured pustules on leaves and heads of wheat plants. The pustules on the leaves will commonly extend down the length of the blade in stripes, hence the name. Later in the season, these yellow urediniospores turn into dark coloured teliospores and the disease might be mistaken for the dark coloured stem rust. Heavy stripe rust infection will result in defoliation and shriveling of seeds as the pathogen breaks the tissue surface and depletes the plant's water supply.

Management

The largest factor in the development of this disease is the weather, and unfortunately, that cannot be controlled. Producers should use varieties of spring wheat with high levels of resistance or use a foliar fungicide at the earliest indication of pustule formation. Foliar fungicides should be reserved for varieties that are susceptible or moderately susceptible, varieties with moderate resistance will likely not elicit a cost-effective response. Spraying is time-sensitive and should be applied before the rust covers more than 5 per cent of the flag leaf surface.

Figure 4.46 Stripe rust on wheat

Figure 4.47 Leaf and stripe rust on wheat



Septoria/Stagonospora Leaf Blotch Complex

Septoria tritici - Septoria leaf blotch
Stagonospora nodorum - Stagonospora nodorum blotch
Stagonospora avenae - Stagonospora leaf blotch

This complex of leaf diseases occurs on wheat and other small grains, but there is some host specificity in special forms of certain fungal pathogens as well as with similar pathogen species. Stagonospora avenae f.sp. triticea affects wheat, triticale and barley, but other forms occur on rye and oat. The severity of disease caused by S. tritici and S. nodorum will increase during wet growing seasons and producers will see the most loss to their yield and quality. Yield loss to stagonospora leaf blotch is usually lower due to symptoms not being expressed until the crop starts to ripen. This disease also tends to be found in eastern Saskatchewan and not throughout the province.

Disease Cycle

The fungal pathogens responsible for these diseases are seed-borne and overwinter on crop residue or winter wheat plants. Conidia (asexual spores) and ascospores (sexual spores) initiate infection both in the fall on winter cereals and on spring-seeded cereals. Spore producing structures called pycnidia are produced on necrotic leaf and glume tissue during wet conditions. These spores spread by rain splash. These diseases prefer wet, windy weather with temperatures around 15-27 C. Dry hot weather will halt any disease development and allow the crop to mature without yield penalties.

Symptoms and Scouting

Septoria leaf blotch (*S. tritici)* is initially seen as yellow flecks that first appear on the lower leaves, especially on leaves in contact with the soil. Spots develop into yellow, greyish-white or brown blotches on all plant parts above ground. Leaves have yellow-bordered lesions that are restricted by the veins. Development of lesions is longitudinal with parallel sides and blunt ends. Elongated blotches range up to five to 15 mm and eventually join together.

Leaf lesions caused by stagonospora nodorum blotch are usually light with dark margins and are less restricted than septoria leaf blotch lesions. *Stagonospora nodorum* may also cause blotches on the glumes and nodes as the plants mature. Glume infections often originate at the tips and spread downwards as purplish-brown to grey lesions with dark pycnidia. Yellow flecks appear on the leaves and enlarge into greyish-brown oval or lens-shaped blotches with a yellow border. Inconspicuous pycnidia are more likely attributed to stagonospora leaf blotch. Refer to "Typical symptoms of cereal leaf spot diseases" figure under Net Blotch of Barley.

Management

There are no commercially available cultivars of wheat that are resistant, durum wheat has been observed to be less susceptible to septoria blotches than bread wheat. Since the disease is seed- borne, clean seed should be used whenever possible and should be tested after years of high leaf disease incidence. Disease prevalence is greater with conventional tillage than reduced tillage. Septoria leaf blotch will be less prevalent when non-cereals are grown for at least two years. Foliar fungicides can be used against this disease.

Figure 4.48 Septoria tritici infection with pycnidia in the lesion

Courtesy of: University of Saskatchewan

Figure 4.49 Septoria tritici infection with pycnidia in the lesion

Courtesy of: University of Saskatchewan

Figure 4.50 Septoria tritici infection with pycnidia in the lesion

Courtesy of: University of Saskatchewan

Figure 4.51 Stagnospora nodorum

Smut, Loose

Ustilago tritici

Loose smut is found wherever wheat is grown, but incidence will be higher in more humid regions. The pathogen has several virulent races that attack different wheat cultivars. The fungal spores of loose smut are usually dispersed before the crop matures and this helps prevent them from accumulating on healthy seed. Therefore, the quality of the grain is rarely affected, but yield loss is directly related to the percentage of infected heads.

Disease Cycle

The infection begins at flowering. Spores that land on the floret germinate, and the developing mycelium penetrates the ovary and establishes itself within the embryo. As the seed matures, the mycelium becomes dormant. Infected seed does not differ from healthy seed and cannot be detected at this point by the human eye. When an infected seed germinates, the mycelium begins growing again and invades the growing point of the seedling. As the head begins to form, there is a lot of fungus growth and a mass of spores will develop instead of a normal spikelet. The spores mature by heading time and are dispersed by wind and rain. Any spores that land on the florets of healthy plants complete the life cycle and begin it anew.

Symptoms and Scouting

Symptoms are only noticeable on heads when the spore masses are present and readily spread by wind and rain. Before heading occurs, infected plants may be slightly stunted in some cultivars, but this can have multiple causes. Infected and healthy heads will emerge simultaneously, but infected heads will have all parts except the rachis replaced with a mass of dark brown spores. As the crop matures, they will blow away and leave only a trace of dark spores and remnants of the glumes or awns because the normal plant tissue is usually completely destroyed.

Management

Loose smut can be easily controlled by using resistant varieties, using smut free seed or by applying a systemic seed treatment fungicide. Seed that is being saved on farm and being considered for the following year's seed source should be tested by an accredited lab to confirm the presence or absence of smut in the seed.

Figure 4.52 Loose smut on wheat

Figure 4.53 Loose smut infection beginning on wheat head

Take-All

Gaeumannomyces graminis

Take-all commonly occurs in wheat crops from the west coast across to the maritime provinces. Barley, rye and a large number of grasses can also be infected. The disease typically follows the breaking of native or cultivated grasslands and is the most severe when wheat is grown continuously in the same field for multiple years. The fungal pathogen overwinters on infected plant residue and prefers warm soil temperatures to facilitate infection of young wheat seedlings. Not using proper management strategies could result in losses of 20-30 per cent when severe.

Figure 4.54 Take-all

Disease Cycle

The pathogen that causes take-all overwinters as mycelium in infected plants or crop residue. Hyphae begin to develop on the infected residue and these structures are very important at initiating the disease in wheat. The runner hyphae grow from root to root. Infection can occur throughout the growing season but favours soil temperatures of 12-20 C and high soil moisture. This fungus also prefers alkaline, compacted, poorly drained, and nutrient deficient soils. The earlier the infection begins the more severe the damage will be. Since the pathogen is confined to the soil and crop residue the only field to field transmission that can occur is through infested soil or crop residue on equipment.

Symptoms and Scouting

Figure 4.55 Symptoms of take-all in wheat

Take-all disease causes brown discolouration of the vascular tissue, and coarse, dark hyphae may be observed on the roots. Severely diseased plants will be stunted, produce less tillers and often die prematurely. The disease will also cause "whiteheads," which often occur in obvious patches. These heads will be empty or contain shriveled kernels. Infected roots will be dark brown to shiny black and may be almost completely rotten. Plants will easily pull from the ground. Take-all can be mistaken for common root rot, however take-all usually can be distinguished by the shiny black appearance of the infected stalks and by the fungal growth under the leaf sheaths. Scouting should occur during the growing season and special attention should be given to low areas that hold water or where plants appear to be stunted or dying.

Management

Using a crop rotation that incorporates non-host crops will help lower the incidence of disease. Improving and maintaining soil nutrient levels, especially for phosphorous and potassium, will help keep the roots healthy and increase their development making it harder for the disease to infiltrate them. Grassy weeds and wheat volunteers should be controlled to stop the disease from continuing within the field.

Figure 4.56 Empty seed heads caused by take-all

Tan Spot

Pyrenophora tritici-repentis

Tan spot is found throughout Canada where wheat is grown. Initially, it was considered a disease of minor importance, but it is now found throughout winter and spring wheat crops from Ontario to the prairies. Tan spot belongs to the leaf spot complex that includes other fungal diseases such as stagonospora/septoria blotches and spot blotch. The symptoms of tan spot can be easily mistaken for other leaf spot diseases except septoria blotch, making lab examination of diseased leaves a requirement to determine the causal agent. Tan spot typically affects wheat and wheat grass and sometimes infects rye and barley, although this is rare. Oats are resistant. The fungal pathogen that causes this disease prefers warm, moist conditions to begin its life cycle. A rise in incidence of tan spot is likely due to more crop residue being left after harvest, poor varietal resistance and changing weather patterns. If left unchecked, severe tan spot infections can drastically damage foliage and result in heavy losses to yield and quality, especially if the infection is on the upper leaves. Severe infections can lead to decreased yields of up to 60 per cent.

Disease Cycle

Although the pathogen is seed-borne, this does not appear to be a major source of inoculum. The main source is the fungus overwintering on crop residue. On the prairies, prolonged periods of subzero temperatures delay development. Mature pseudothecia are found on two-year old stubble.

Ascospores and conidia are produced in the spring and are carried by wind to susceptible young plants. Ascospores contribute more as the initial inoculum. During the growing season, conidia are produced in older lesions on wet leaves and become air-borne as the leaves dry. Several of these cycles can happen in a single growing season. The fungus requires at least six hours of leaf wetness to infect and colonize tissue to continue its life cycle. Temperatures below 20 C will slow development and temperatures exceeding 28 C will completely halt development. Hot dry conditions in July help stop tan spot from being completely devasting to crops that appeared severely infected in the spring.

Symptoms and Scouting

The first signs of tan spot are small, dark brown to black spots appearing on the lower leaves. As the disease progresses, tan oval-shaped lesions develop along the leaf veins. A central dark spot that is the initial site of infection may be visible. Depending on the cultivar grown, a chlorotic halo may develop around the leaf lesions. Under ideal moisture and temperature conditions, the lesions will merge and form irregular blotches similar to stagonospora/septoria leaf blotches. However, tan spot does not develop the dark pycnidia structures like septoria blotch does. Most wheat cultivars in Western Canada are moderately susceptible to the disease and will develop typical tan lesions with dead tissue. If the infection spreads to the head, mature kernels may develop a reddish colour known as red smudge. Red smudge should not be mistaken for the pinkish fungus seen with fusarium head blight infection. Red smudge is most commonly found in durum and favours late season rain, irrigation and warm weather. When scouting fields, look for tan or brown spots or yellow-rimmed blotches on the lower leaves. Later in the season, pay close attention to withered or dead leaves. Examine the heads for infection. Infected seed will appear smaller, shriveled and have a red colouration. Refer to "Typical symptoms of cereal leaf spot diseases" figure under Net Blotch of Barley.

Management

Current wheat cultivars are prone to tan spot, making this not a viable source of control. Using a crop rotation that contains resistant plant types such as canola, flax, oats and pulses will help break the disease cycle and allow for the decomposition of infected residue. Reducing in-crop humidity within the canopy by widening the row spacing could help reduce infection by eliminating the conditions needed for infection. Fungicides can be used to protect a crop from tan spot.

Figure 4.57 Tan spot on wheat stems

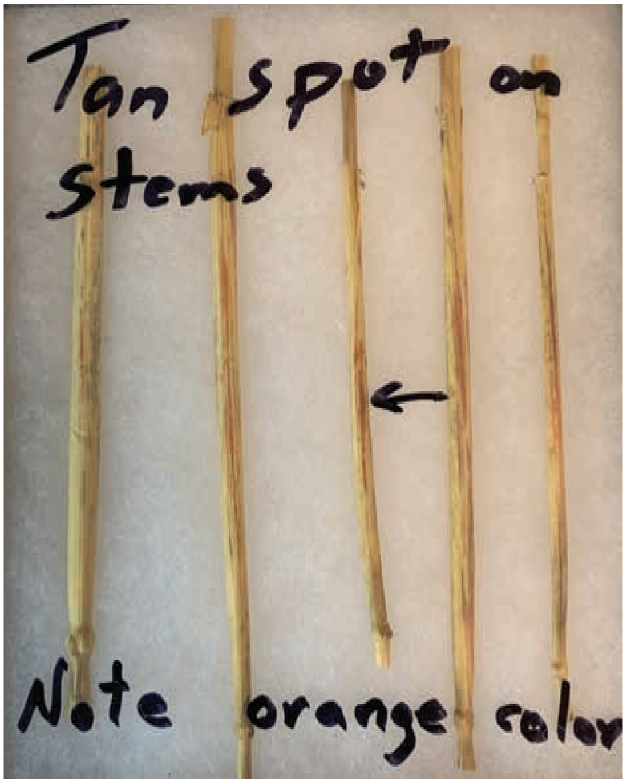


Figure 4.58 Tan spot on wheat leaf

Figure 4.59 Tan spot on wheat (late July)

Figure 4.60 Tan spot on wheat

Figure 4.61 Tan spot pseudothecia on overwintering stems

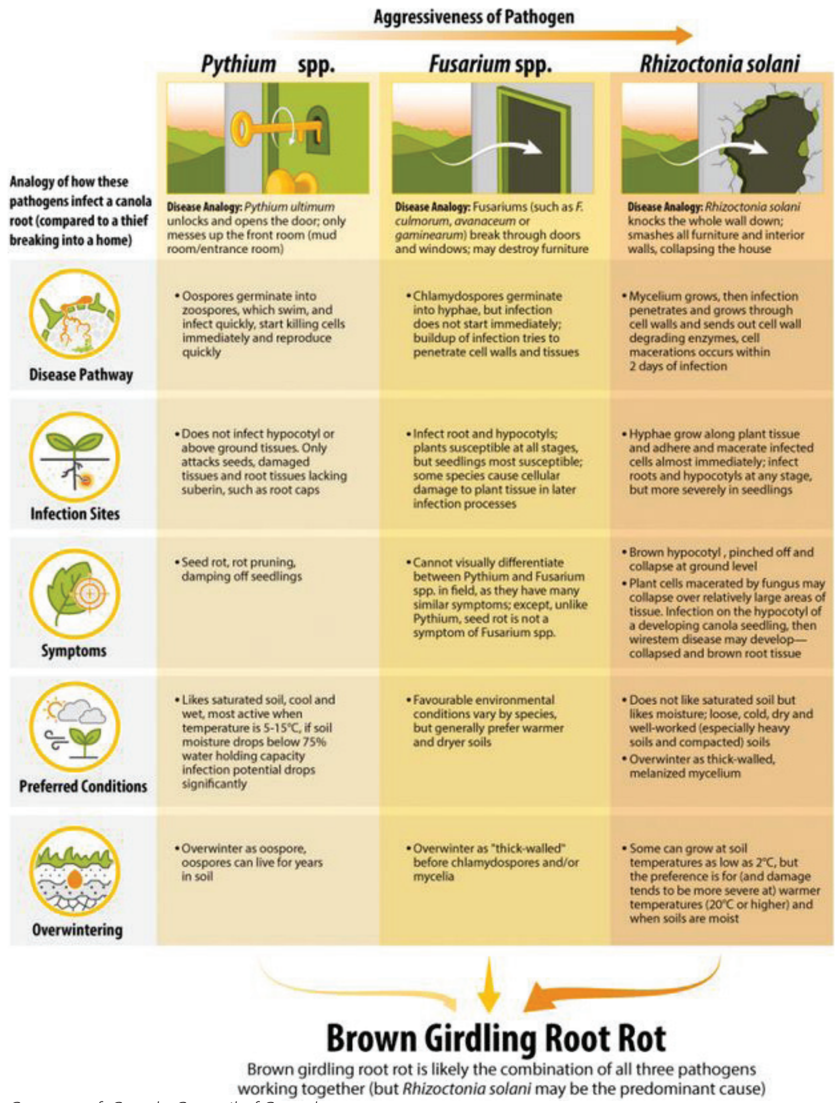
Common Diseases in Canola and Mustard

Brown Girdling Root Rot

Rhizoctonia solani (predominant cause)
Pythium spp.
Fusarium spp.

Brown girdling root rot (BGRR) can be found in prairie oilseed crops but is most prevalent in the Peace River region of Alberta and in B.C. BGRR is caused by a disease complex. Multiple fungi can infect the host plant roots individually or together, leading to disease. Typically, most infections are established by the fungus *Rhizoctonia solani*, while other genera in the disease complex including *Pythium* spp. and *Fusarium* spp. can infect the plant after *Rhizoctonia solani* has established. BGRR can be severe in areas with heavy, low pH soils. Conditions favourable for disease development are wet soil at the early flowering stage, followed by dry, warm weather. When these conditions occur and the pathogen is present, the potential for yield loss is high.

Figure 4.62 Root rot pathogens that infect canola



Courtesy of: Canola Council of Canada

Disease Cycle

Rhizoctonia solani overwinters in the soil as dormant mycelium or sclerotia. When the soil begins to warm up in the spring, the mycelium grows and comes in contact with host roots and hypocotyls. Mycelium grows on the surface of host roots and conglomerates and forms infection cushions. A single infection cushion will produce multiple infection pegs (a specialized cell or type of growth that forms during spore germination). Root infections can lead to the root cortex being destroyed and potentially even the host vascular system being infected. When the root cortex is infected BGRR occurs, while the vascular infection may lead to wirestem.

In the fall, the pathogens causing BGRR once again enter a dormant state to overwinter.

Symptoms and Scouting

The first observable BGRR symptom is light brown lesions with irregular margins on the taproot of the canola plant. As the disease progresses, lesions expand and grow together and eventually girdle the root. Girdling can affect the plant stand, causing uneven maturity, stunted growth, and symptoms of nutrient deficiency. Plant death can occur in extreme cases. Affected plants may display poor pod development and produce small, shrivelled seeds.

Management

Using certified seed is an important control method of BGRR as *Rhizoctonia* is seed-borne. Fungicide seed treatment is also recommended in canola and mustard for early season control. *Brassica napus* (Argentine canola) cultivars are less susceptible to brown girdling root rot than *Brassica rapa* (Polish canola) cultivars.

Figure 4.62 Brown girdling root rot

Courtesy of: Canola Council of Canada

Figure 4.62 Root rot in canola

Courtesy of: Canola Council of Canada

Blackleg

Leptosphaeia maculans
Leptosphaeria biglobosa

Blackleg is a serious disease of canola that can result in significant yield loss. Mustard is an alternate host crop for blackleg. Blackleg is predominantly caused by the fungus Leptosphaeria maculans, but blackleg caused by Leptosphaeria biglobosa can also occur. In addition to canola, this disease can also infect mustard, rutabaga, turnips, as well as brassicaceous vegetable crops and weeds. It can infect cotyledons, leaves, stems and pods. Blackleg occurs globally, preferring warm, humid conditions with frequent rain showers. However, the disease can still be an issue in drier climates. Yield loss can vary significantly depending on the time and severity of infection.

Figure 4.63 Blackleg lesion on canola cotyledon

Figure 4.64 Blackleg leaf lesion

Figure 4.65 Canola cross sections showing blackleg

Figure 4.66 Blackleg on upper branch of canola with pycnidia

Figure 4.67 Blackleg stem canker with pycnidia

Disease Cycle

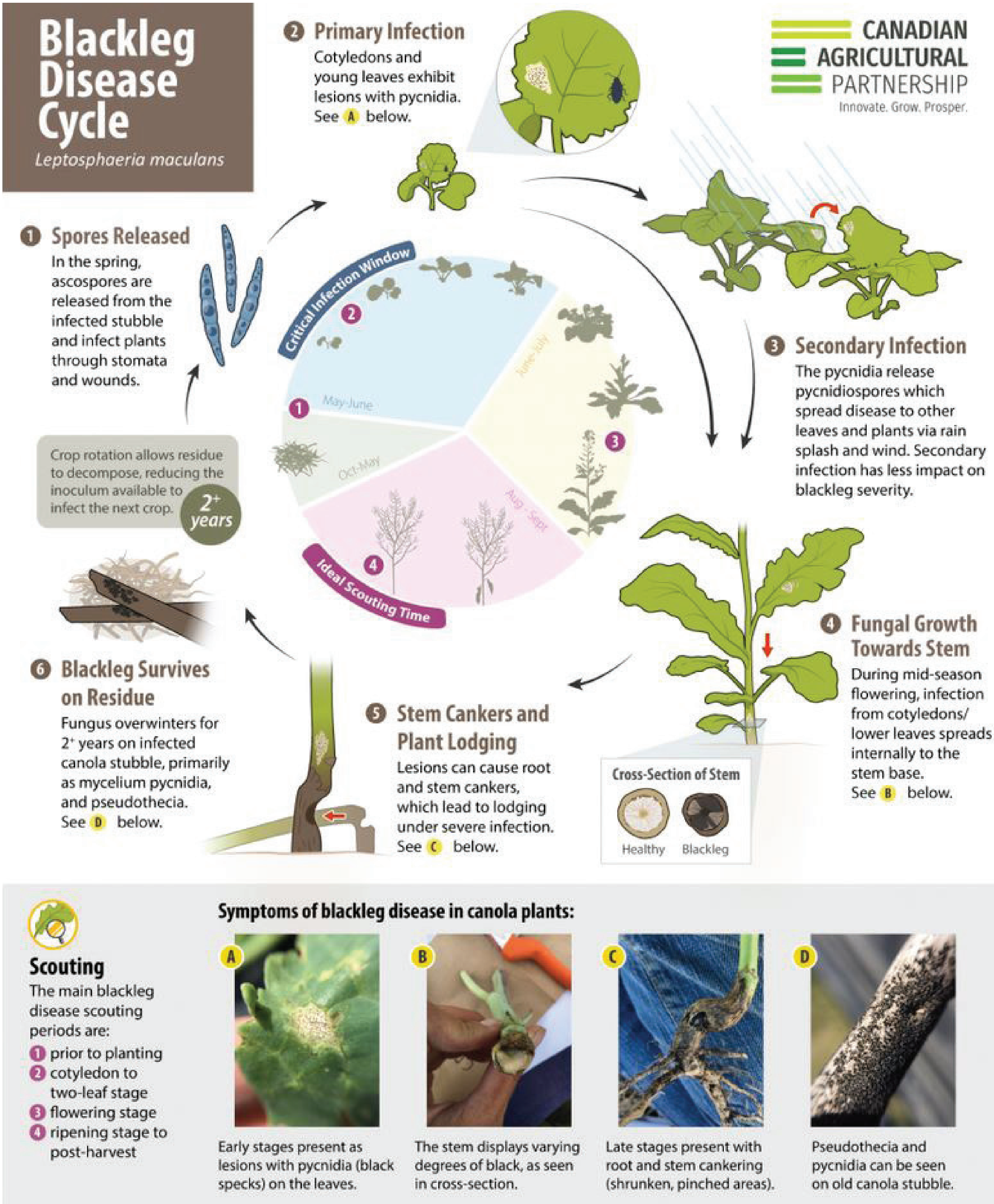
The pathogen overwinters on host stubble as pseudothecia, which are specialized reproductive structures that contain ascospores. In the spring, pseudothecia release ascospores into the air which are then blown by wind to other plants. Ascospore infection occurs on leaves, colonizing the plant through leaf wounds or stomata. The fungus needs the plant to stay alive and will colonize the host leaf or cotyledon and then move through the petiole into the stem. At this point the fungus changes to killing and feeding on plant tissue. This causes leaf and stem lesions, called cankers. These lesions have a specialized reproductive structure called pycnidia in them that can exude pycnidiospores. The pycnidiospores can infect the stem or leaves again, causing a secondary infection or can spread disease to other plants through rain splash and wind. Secondary infection generally has limited impact on the overall blackleg disease severity.

Symptoms and Scouting

Symptoms first appear on leaves as grey or white lesions that are round or irregularly shaped, populated with small black dots resembling flecks of pepper, called pycnidia. Stem lesions can be elongated, sunken brown, and may have pycnidia present. Lesions can also appear on other parts of the plant, including upper branches and pods. Blackleg can affect the quality of canola seed as infected pods can ripen early and cause the seeds to be shriveled and pale grey. Cankers commonly appear at the base of the stem once the disease is more developed. These cankers have the potential to girdle the stem causing premature ripening.

A yield loss model created by the University of Alberta was used to create a Blackleg Yield Loss Calculator that is available on the Canola Council of Canada's website. The model shows the expected yield decrease using a disease severity scale. Every unit of increase in disease severity can cause a 17.2 per cent loss in seed yield.

Figure 4.68 Life cycle diagram of blackleg



Courtesy of: Canola Council of Canada

Blackleg Scouting Tips

Adapted from Canola Council of Canada's Canola Encyclopedia

There are three main scouting periods for blackleg disease during the growing season:

Prior to planting:

- Examine canola residue to see if pseudothecia are present.

Vegetative stage (three to six leaves):

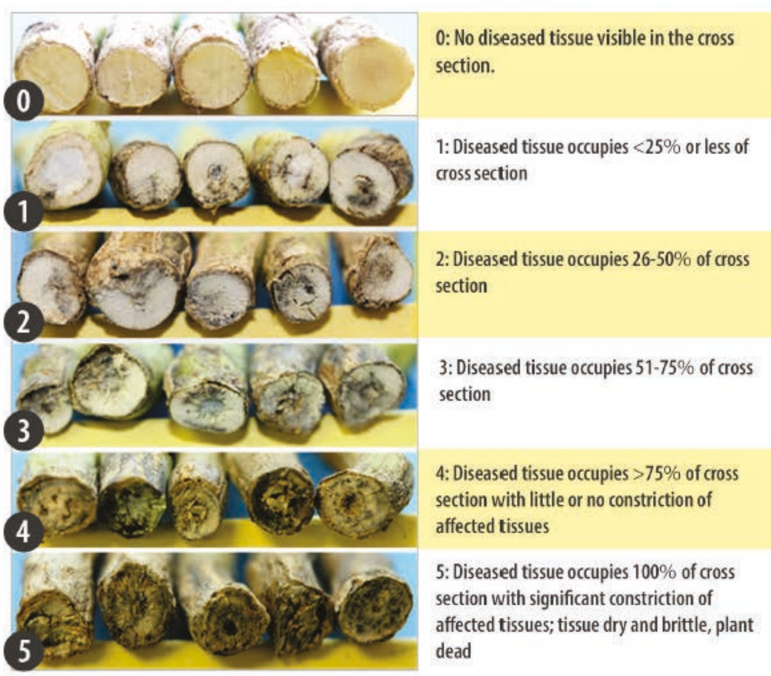
- Scout using a 'w' pattern through the field, starting at the field's edge. Focus on edges where new canola residue may be present in the adjacent field.
- Examine at least 50 plants for the presence of lesions. If lesions are found on more than 10 per cent of plants, then there is a risk of significant disease development.

At swathing:

- At this point, it is too late to control the disease, but assessing disease presence and the effectiveness of the blackleg-resistant variety can help guide future variety rotation decisions.
- This is the best time to scout for the disease as the basal cankers which cause significant yield loss are easily seen.
- Pull up at least 50 plants in a 'w' pattern as described above.
- Using a pair of hand clippers, clip at the base of the stem/top of root and look for blackened tissue inside the crown of the stem. The amount of infection present will help assess the level of risk and determine the best management practices for that field in following years.
- Disease severity determined using the rating scale below can be used to assess the effectiveness of the blackleg-resistant variety used and can help guide variety rotation decisions.

The blackleg rating scale can be used to assess the severity of the infection at swathing time:

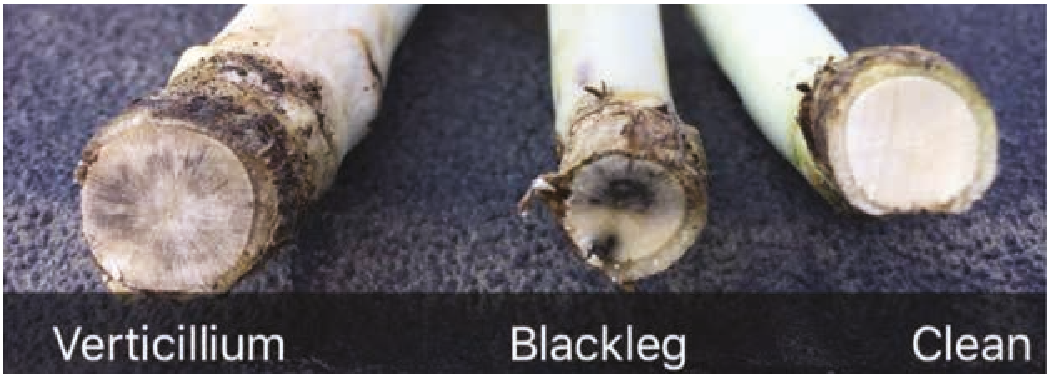
Figure 4.69 Blackleg rating scale



Courtesy of: Canola Council of Canada

Figure 4.70 Clipping location for blackleg

Figure 4.71 Blackleg vs. Verticillium



Courtesy of: Canola Council of Canada

Management

Crop rotation is one of the most important management tools for blackleg control. Multiple years between canola crops can help lower pathogen levels by allowing for the decomposition of infected residue. Another management tool is proper scouting. Blackleg can be confused with other diseases, so proper identification is key. Using resistant cultivars is important but can also lead to the breakdown of resistance. Scouting is still important when resistant cultivars are grown as a fungicide application may still be warranted. Rotating cultivars can reduce selection pressure and improve long-term blackleg field management. Other options include the use of fungicide, and control of brassica weeds that are also hosts. Please refer to the Guide to Crop Protection for available fungicide options for canola and mustard.

Figure 4.72 Best Management Practices for reducing the risk of blackleg

If the previous canola crop was infected severely, resulting in yield loss from blackleg, the following practices should be considered to assess the risk and manage the disease.

Canola in rotation.
Tightened canola rotations allow for blackleg inoculum to build within the field. Extending canola rotations (greater than a two-year break from canola) will allow more time for inoculum levels to decline, as old canola stubble decomposes.

Scout for the disease.
Look for internal stem blackening at ground level during swathing or straight cutting, and for pseudothecia on previous year's canola residue prior to seeding. The presence of either will help determine the risk of infection in the next canola crop.

Field resistance used.
Plant either "Resistant" (R) or "Moderately Resistant" (MR) cultivars. Resistant cultivars outperform susceptible or bin run seed.

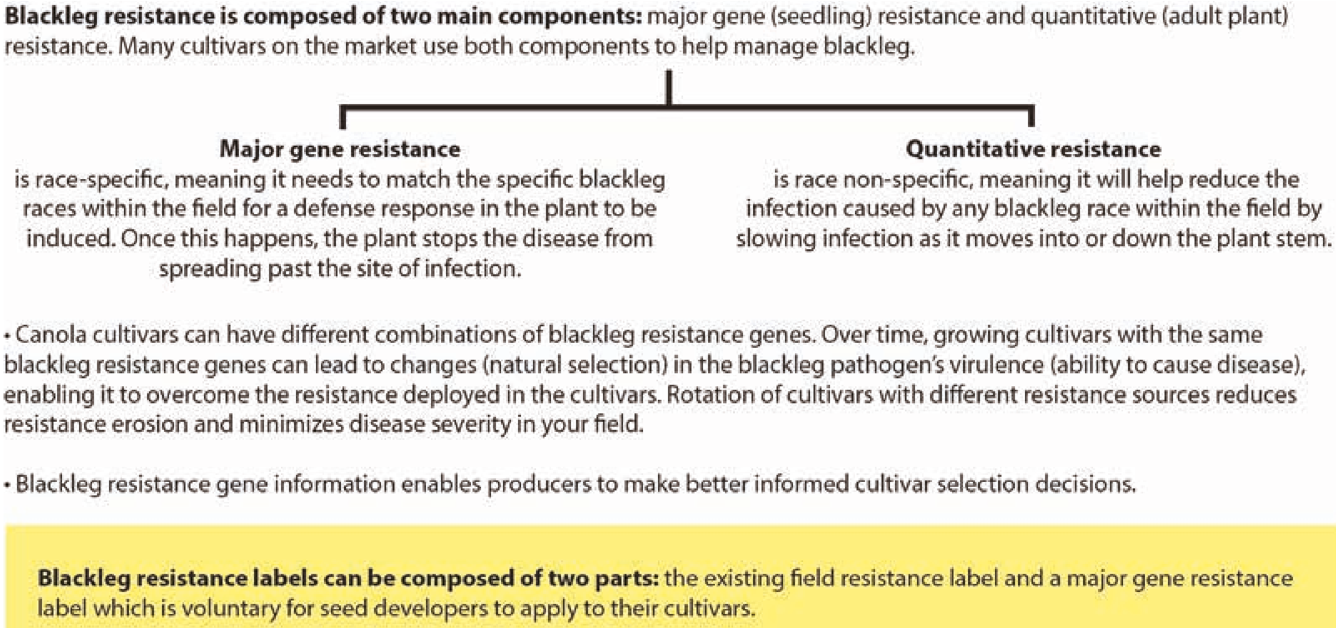
Resistance source rotation.
Rotate cultivars by their major blackleg resistance gene. Similar to herbicide group rotation, rotating blackleg major resistance genes will slow the *L. maculans* races from becoming resistant towards these genes. Use a *L. maculans* race identification test to determine predominant *L. maculans* races in the field to help match appropriate resistance sources.

Fungicide use.
The option to add a fungicide seed treatment is available for many canola cultivars. A seed treatment fungicide protects plants from blackleg when they are most susceptible. An early season foliar fungicide application can help to prevent yield losses if applied during the cotyledon to two-leaf stage. Later foliar applications can help to reduce the inoculum in the field.

Courtesy of: Canola Council of Canada

blackleg-management-guide (canolacouncil.org)

Figure 4.73 Decoding blackleg resistance



Blackleg resistance is composed of two main components: major gene (seedling) resistance and quantitative (adult plant) resistance. Many cultivars on the market use both components to help manage blackleg.

Major gene resistance
is race-specific, meaning it needs to match the specific blackleg races within the field for a defense response in the plant to be induced. Once this happens, the plant stops the disease from spreading past the site of infection.

Quantitative resistance
is race non-specific, meaning it will help reduce the infection caused by any blackleg race within the field by slowing infection as it moves into or down the plant stem.

- Canola cultivars can have different combinations of blackleg resistance genes. Over time, growing cultivars with the same blackleg resistance genes can lead to changes (natural selection) in the blackleg pathogen's virulence (ability to cause disease), enabling it to overcome the resistance deployed in the cultivars. Rotation of cultivars with different resistance sources reduces resistance erosion and minimizes disease severity in your field.

- Blackleg resistance gene information enables producers to make better informed cultivar selection decisions.

Blackleg resistance labels can be composed of two parts: the existing field resistance label and a major gene resistance label which is voluntary for seed developers to apply to their cultivars.

Courtesy of: Canola Council of Canada https://www.canolacouncil.org/canola-watch/2019/02/08/interpreting-blackleg-race-id-test-results/
blackleg-management-guide (canolacouncil.org)

Clubroot

Plasmodiophora brassicae

Clubroot is a serious disease that affects the roots of brassica field crops, vegetables and weeds. It is caused by a soil-borne protist called *Plasmodiophora brassicae*. The pathogen causes galls to form on the roots, which can cause premature death of the plant. Yield loss is dependent upon multiple factors, including soil moisture, temperature, spore load, soil pH, time of infection, soil texture, host genotype and pathogen races.

Disease Cycle

The clubroot pathogen overwinters in the soil as resting spores. In the spring, these spores germinate and produce zoospores, which can swim short distances in water in the soil and find root hairs to infect. After the primary infection, the pathogen produces secondary zoospores, which are then released to infect the root cortex. The pathogen stimulates cell division and cell growth, both of which lead to the development of galls. As the galls decay in the soil, millions of resting spores are left behind. It has been estimated that resting spores can survive in the soil for up to 20 years, but the most commonly estimated population half-life is 4 years.

Symptoms and Scouting

Clubroot symptoms are present on the roots before the rest of the plant, which is why digging up plants to check for disease symptoms is important. The roots of infected plants will be malformed and will have galls. Infected plants can also have aboveground symptoms, including yellowing and premature ripening.

When scouting, the best areas to inspect are field entrances, high-traffic areas and locations where water pooling occurs. While the most reliable way to confirm clubroot is by identifying galls on the roots, there is soil and plant testing available for pathogen DNA detection. There are currently multiple labs in Canada that provide this testing. A list of labs is available online in Canola Council of Canada's Canola Encyclopedia under Clubroot.

Management

Multiple strategies can be used for clubroot management, but one of the most important is implementing a proper crop rotation. Every time a susceptible crop is grown, more resting spores will be returned to the soil, increasing the pathogen population and potential yield loss the next time a susceptible crop is grown. Using clubroot-resistant varieties, minimizing soil movement or implementing sanitization practices, going to infected fields last with equipment and vehicles, patch-seeding perennial grass in contained clubroot areas, and conducting regular scouting and testing are other good management strategies.

Interpreting a Clubroot Soil Test Result

The results of a clubroot test may look different depending on the lab conducting the test. Some labs offer a "yes" or "no" type of test (PCR), while other tests will indicate the concentration of the pathogen in the soil (expressed as spores per gram of soil: qPCR).

- For a PCR test, a positive result indicates that the pathogen is present in the field. When this occurs, it is important to implement proactive management strategies to keep pathogen levels low and prevent spreading the pathogen to new fields or new areas.
    - A negative test result means that the pathogen was not detected in the area where the soil was collected. This does not mean that the pathogen is not present in the field, due to the limitations of the test and the potential for a false negative.
- When the concentration of the pathogen is determined, it can provide you with an estimate of the pathogen level in the field. If pathogen levels are high, this indicates that there is a higher potential for larger yield losses. However, due to variable occurrences of the pathogen in the field and the limitations of DNA-based testing, this information cannot be used to estimate the potential yield loss due to clubroot.
    - A minimum two-year break (three-year crop rotation) from a susceptible crop or weed species will allow the pathogen population to reduce over time. When pathogen levels are high, greater than 100,000 spores per gram of soil, additional clubroot management strategies are necessary, as crop rotation on its own will not effectively reduce spore levels to a manageable level.
    - The level of the pathogen may vary over the growing season, particularly when a susceptible host crop is grown. If you use DNA-based soil testing to monitor pathogen levels over time, always collect soil samples from the same location and at the same time of the year.
- It is important to remember that clubroot management needs to be proactive and should include the use of clubroot-resistant varieties in extended crop rotations to keep pathogen levels low whenever the pathogen is present in the field or within the region.

For specific details on sample testing, please inquire with your commercial or provincial crop protection lab.

Types of DNA Soil Testing

- Polymerase Chain Reaction (PCR): PCR soil testing for clubroot relies on the amplification and detection of the clubroot pathogen DNA. This test gives a positive or negative result and can be used to indicate whether or not the clubroot pathogen is present above the limit of detection in the area where the soil was collected.
- Quantitative Polymerase Chain Reaction (qPCR): qPCR testing relies on the same basic principles of a PCR test, but allows for the quantification of the amount of pathogen DNA present in the soil sample. The amount of DNA detected is then used to approximate how many spores are present in a gram of the soil tested.

The limit of detection for both PCR and qPCR clubroot tests are approximately 1,000 spores per gram of soil. These tests are not able to differentiate between different strains or pathotypes of clubroot.

Courtesy of: Governments of Alberta Saskatchewan and Manitoba interpreting a clubroot soil test results factsheet

Figure 4.74 Large and small clubroot galls

Figure 4.75 Mature clubroot gall on canola


Figure 4.76 Variety of clubroot gall shapes and sizes

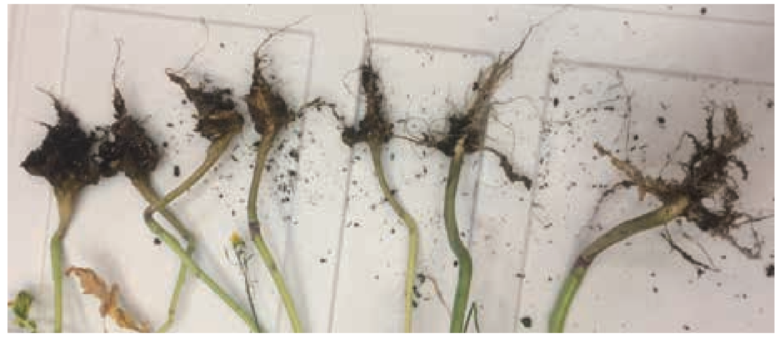


Figure 4.77 Variety of clubroot gall shapes and sizes


Figure 4.78 Premature ripening caused by clubroot on canola

Fusarium Wilt

Fusarium oxysporum

Fusarium wilt is a relatively uncommon fungal disease in Saskatchewan but can still be present in some fields. It is more likely to affect a plant that is already stressed from other conditions.

Disease Cycle

Fusarium oxysporum overwinters as resting spores in the soil or on infected crop residue. Spores germinate in the spring and attack the roots of growing canola plants. These spores eventually infect the vascular tissue blocking the xylem and flow of water up the stem. Spores are formed on other plant parts and are returned to the soil when the plants die and fall to the ground. These spores can survive for over 10 years in the soil.

Symptoms and Scouting

The main symptoms of fusarium wilt are wilting and yellow and dark discolouration often only on one side of the stem. Severely infected plants may have very poor seed set and die prematurely.

Management

Reducing inoculum levels with crop rotation is one of the best management practices for fusarium wilt. All canola cultivars are resistant to fusarium wilt as they have a resistant gene. Using certified seed and planting into warm soil are also management strategies that can help reduce stress and decrease the chance of infection.


Figure 4.79 Fusarium wilt symptoms on canola stem


Figure 4.80 Senescing leaf from fusarium wilt infected plant

Courtesy of: Canola Council of Canada


Figure 4.81 Fusarium wilt infected plant

Courtesy of: Canola Council of Canada

Grey Stem

Pseudocercosporella capsellae

Grey stem is a common disease of canola in Saskatchewan but causes little economic impact. The fungus can infect many plants within the Brassicaceae family but typically develops so late in the season that there is little to no impact on yield or quality.

Figure 4.82 Grey stem in canola

Figure 4.83 Grey stem in canola

Disease Cycle

In the spring, fungus that has overwintered as a thick-walled mycelium on infected crop residue will produce wind-borne spores to infect host plants. Lesions begin to develop on the lower leaves of the plant that produce wind-borne spores. These will begin to re-infect other parts of the plant including the stem where we see symptoms late in the season. Conidia (asexual spores) can spread over short distances by rain splash.

Symptoms and Scouting

Lesions first appear on leaves as small grey spots that grow over time. Later in the season, purple or gray lesions will begin to appear on the pods and stem. At harvest, stems may be completely grey or purple in colour. Differentiating between grey stem, blackleg, verticillium stripe and saprophytic growth can be difficult later in the season. Stems can be sent away to a lab for confirmation.

Management

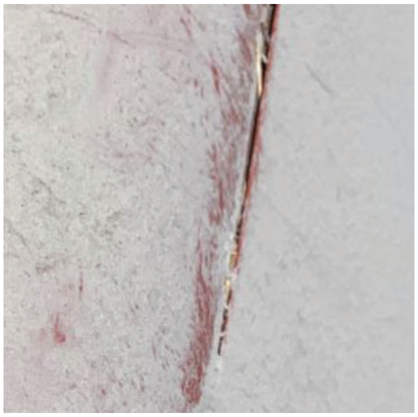
Grey stem can be managed through crop rotation, control of alternate host plants (including shepherd's purse, ball mustard and wild mustard), integrated weed management and optimizing inputs and growing conditions for the crop.

Powdery Mildew

Erysiphe cruciferarum

Powdery mildew is caused by a fungus called *Erysiphe cruciferarum*. It is generally not a yield-limiting disease as most infections happen late in the season. Powdery mildew does not kill plants because it is an obligate pathogen that causes disease but cannot survive or replicate outside of its host. The disease can be worse when the plant is stressed, possibly due to poor growing conditions or poor nutrient availability.

Figure 4.84 Powdery mildew spores on a combine



Disease Cycle

The pathogen overwinters as cleistothecia which germinate in the spring to produce ascospores. Conidia are produced on infected plants and can be carried by the wind to new fields. When ascospores or conidia land on the upper surface of the leaves or stems along with a relative humidity between 50 and 90 per cent and temperatures of 20 to 27 C, the disease cycle can begin.

Figure 4.85 Powdery mildew on canola

Symptoms and Scouting

Symptoms are not always obvious and begin on the leaves. As the disease progresses, white fungal growth can be found on the leaves, stems and pods. Symptoms are most obvious at swathing or harvest timing when equipment gets coated in a powdery white dust.

Management

At this time there is very little known about powdery mildew management and there are no fungicides registered to control the disease.

Sclerotinia Stem Rot (White Mould)

Sclerotinia sclerotiorum

Canola fields with plants infected by the fungus *Sclerotinia sclerotiorum* can have significant yield loss. Sclerotinia has a wide host range, including canola, mustard, chickpea, faba bean, field pea, lentils, and all broadleaf weeds. The severity of the disease varies significantly from year to year depending on environmental conditions and the amount of inoculum. Sclerotinia prefers environmental conditions for development where temperatures range from 10 to 30 C, along with high humidity and moist soil.

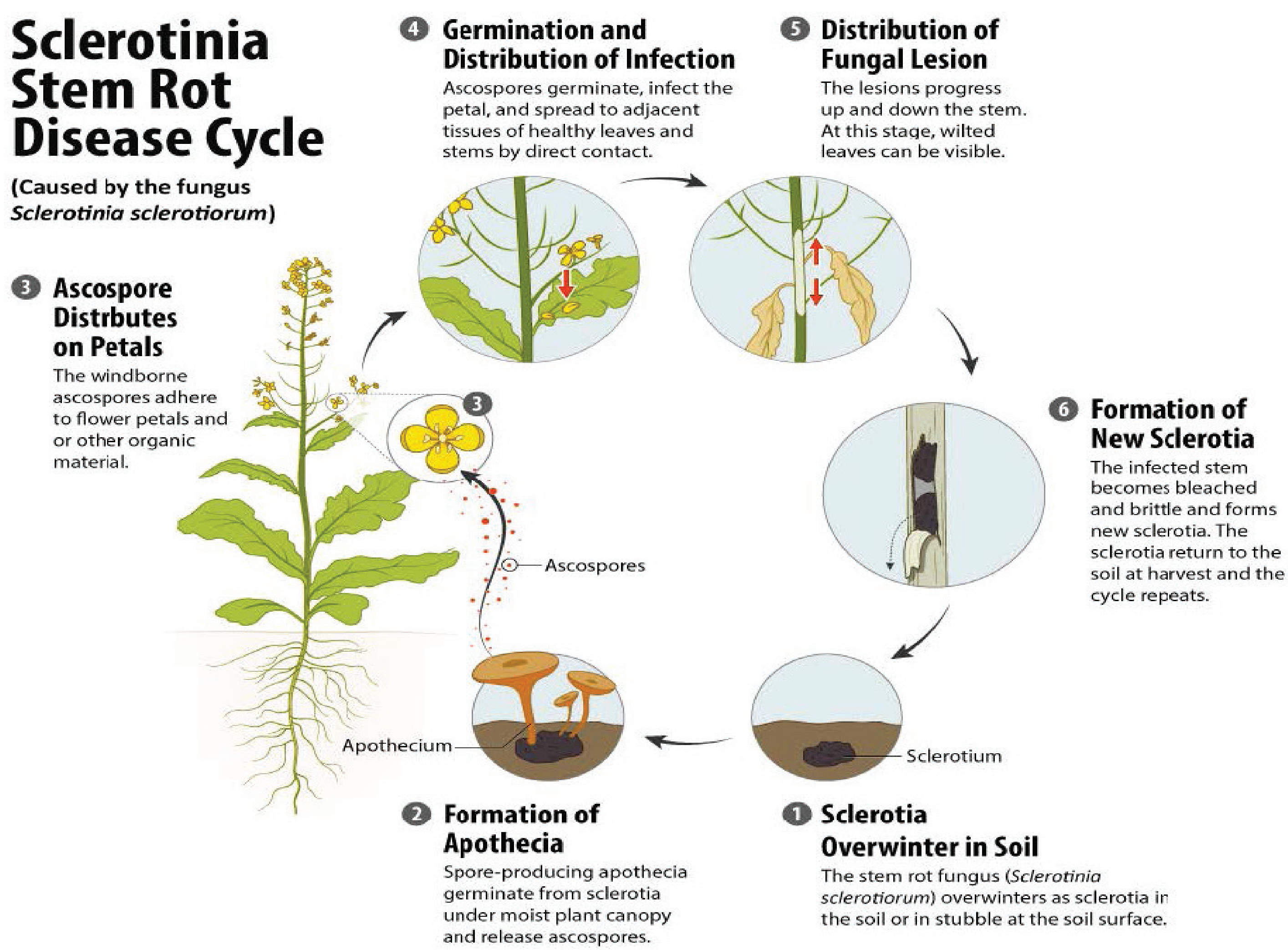
Disease Cycle

Sclerotinia overwinters as sclerotia in the soil which can survive for several years. Sclerotia germinate, producing apothecia. The apothecia produce structures that contain ascospores. Ascospores are released and land and then germinate on flower petals and other organic material and then spread to adjacent tissues of healthy leaves and stems. Ascospores utilize the dying plant tissue as an external nutrient source to facilitate penetration, which is the most common pathway for infection. Infected flower petals that fall and land in the crevice of the stem and branch are a classic starting point for a sclerotinia lesion to form on a canola stem. The lesions progress up and down the stem. The pathogen produces sclerotia on and within infected stems to overwinter.

Symptoms and Scouting

Sclerotinia symptoms develop later in the season after flowering, and originally show up as soft, watery lesions on the leaves and stems. Plants wilt and ripen prematurely making diseased plants a noticeable straw or white colour in an otherwise green crop. Stems of infected plants will eventually start to shred, and the pods will shatter very easily. If infected stems are split open, you will often find white moldy growth and black sclerotia.

Figure 4.86 Life cycle diagram of Sclerotinia sclerotiorum



Courtesy of: Canola Council of Canada

Sclerotinia Rating Scale

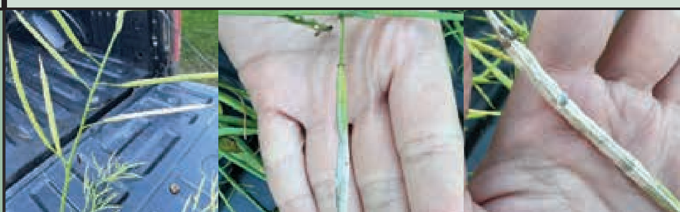
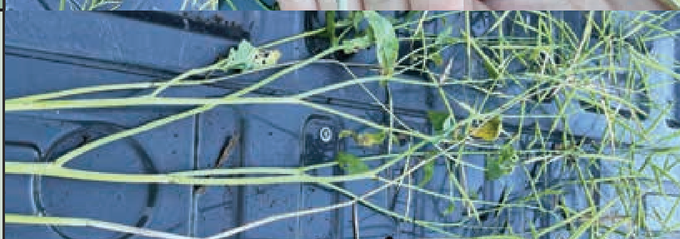
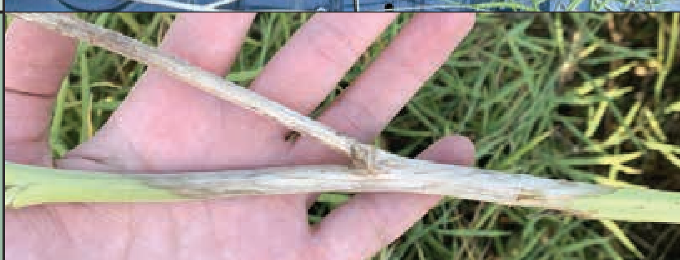
For sclerotinia stem rot of canola, severity assessments are based on an infection's possible impact on yield. The severity ratings will take into account the position of the lesion and the potential of that lesion to impact the yield of the infected plant. Lower main stem lesions have the potential to affect the entire plant and will lead to higher levels of yield loss than pod or branch infections which only impact a part of the plant.

As a rule of thumb, the potential yield loss in a field can be determined by:

per cent potential yield loss = per cent disease incidence x 0.5
(where disease incidence = per cent of plants infected)

For example, a canola field with 50 per cent of the plants infected with sclerotinia stem rot would have an approximate yield loss of 25 per cent (50 per cent disease incidence x 0.50 = 25 per cent). The actual yield losses depend on the environmental conditions, canopy structure, cultivar and time of infection.

Table 4.2 Sclerotinia severity rating scale

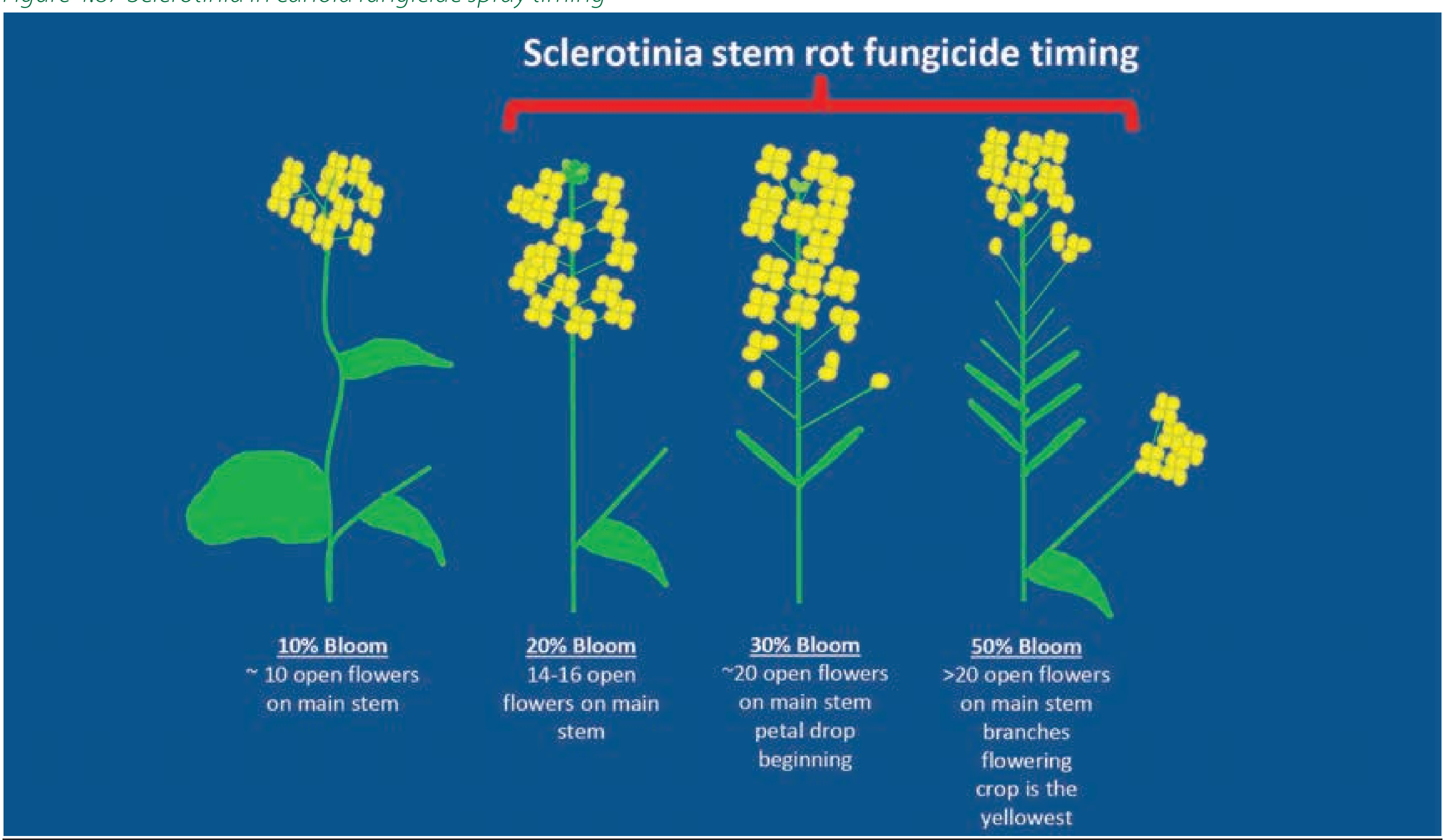
Disease Rating	Lesion Location	Symptoms
0	None	No symptoms
1		Infection of pods only
2		Lesion situated on main stem or branch(es) with potential to affect up to ¼ of seed formation and filling on plant
3		Lesion situated on main stem or on a number of branches with potential to affect up to ½ of seed formation and filling on plant
4		Lesion situated on main stem or on a number of branches with potential to affect up to 3/4 of seed formation and filling on plant
5		Main stem lesion with potential effects on seed formation and filling of entire plant

Adapted from Kutcher, H.R. and T.M. Wolf. 2006. Low-drift fungicide application technology for sclerotinia stem rot control in canola. Crop Protection 25: 640-646

Table 4.3 Sclerotinia in canola fungicide spray scale

Risk Factor	Possible Answers	Risk Points
Number of years since last canola crop	> 6 years	0
	3 - 6 years	5
	1- 2 years	10
Disease incidence in last host crop • **Keep accurate records** • **Refer to Saskatchewan canola disease survey data**	None	0
	Low (1 - 10%)	5
	Moderate (11 - 30%)	10
	High (31 - 100%)	15
Crop density	Low	0
	Normal	5
	High	10
Rain in the last two weeks	<10 mm (<0.4"')	0
	10 - 30 mm (0.4 - 1.2")	5
	>30 mm (>1.2")	10
Weather forecast	Low chance of precipitation	0
	Uncertain or variable	10
	High change of precipitation	15
Regional risk of apothecia development? • **Apothecia or sclerotinia depots** • **Canola petal testing**	None found	0
	Low numbers	10
	High numbers	15
Total Risk Points =		(_______)
If risk points total 40 or higher, it is likely worth spraying. If risk points total less than 40, it is not likely worth spraying.		

Figure 4.87 Sclerotinia in canola fungicide spray timing



Management

Crop rotation with non-host crops is an important part of managing sclerotinia to minimize the amount of sclerotia in the soil. There are multiple host crops for sclerotinia so crop rotation will only work when rotating to non-susceptible crops such as cereals. One effective in-season management tool is a fungicide application. Fungicides must be applied before disease symptoms are present and are generally applied between 20 and 50 percent bloom.

Figure 4.88 Apothecia

Figure 4.89 Sclerotia bodies inside canola stem

Figure 4.90 Sclerotia body formed outside canola stem

Figure 4.91 Sclerotinia white mould growth on canola pod

Figure 4.92 Diseased petal infecting canola stem with sclerotinia

Figure 4.93 Sclerotinia stem rot on canola stem

Figure 4.94 Plant death from sclerotinia

Wirestem

Rhizoctonia solani (predominant cause)
Pythium spp.
Fusarium spp.

Figure 4.95 Wirestem in canola

Wirestem is generally caused by the fungus *Rhizoctonia solani* but can also be caused by *Pythium* spp. and *Fusarium* spp. These are the same pathogens that cause brown girdling root rot, but wirestem typically infects plants at the seedling stage. Using treated seed provides temporary protection for the plants from BGRR, wirestem and root rot. Root rot is more likely to affect established plants. The greatest damage comes from seeding into cold soils early in the season as this permits the pathogen to have a competitive advantage over the host due to poor growing conditions for the host.

Disease Cycle

Rhizoctonia solani overwinters as mycelium. When the soil begins to warm in the spring, mycelium grows and comes in contact with canola roots and hypocotyls. The mycelium grows on the canola tissue surface producing multiple infections. Plant cells are infected by the fungus and may eventually collapse. The root infections can lead to brown girdling root rot whereas hypocotyl infection is more likely to lead to wirestem. In fall, the pathogens enter a dormant state to overwinter.

Symptoms and Scouting

Symptoms are not always obvious and can appear up until the four-leaf stage. Seedlings will emerge but the roots underneath the soil surface will start to deteriorate, and the disease will eventually move up into the hypocotyl or stem. The canola plant above ground may become purple or discoloured. The stem loses integrity, and the tissues collapse leading to plant death.

Management

Including a proper three- or four-year rotation between canola and mustard crops is always a good practice for disease management. To help manage wirestem, a fungicidal seed treatment for *Rhizoctonia* spp. can be used to help protect seedlings for a time. To further help prevent wirestem, seed into warm soil and avoid seeding deep or using excessive seed-placed fertilizer.

Verticillium Stripe

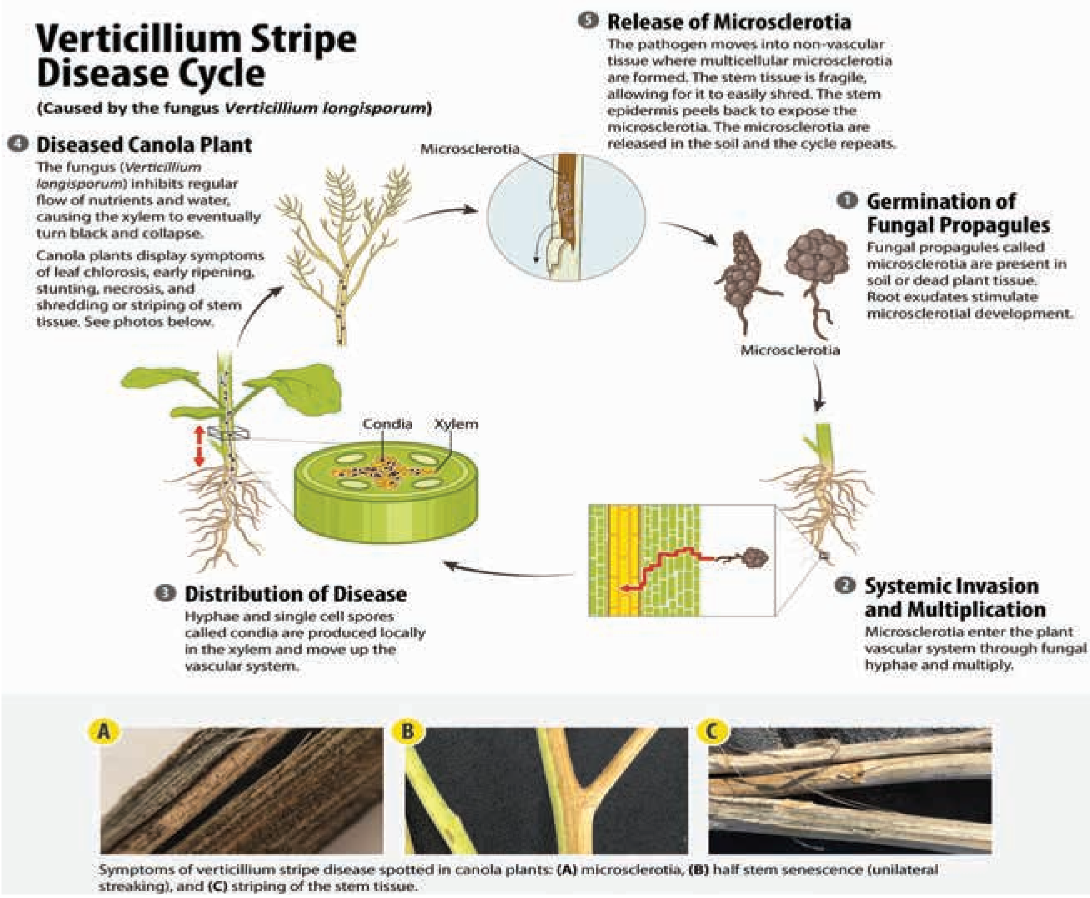
Verticillium longisporum

Saskatchewan has recently begun monitoring verticillium stripe and its presence in the province is still being understood. It is caused by the fungal species *Verticillium longisprorum*. Other field crops in Saskatchewan have not been confirmed as hosts for verticillium stripe. In Europe, other confirmed hosts include wild mustard, broccoli, radish, horseradish and cabbage. Verticillium stripe prefers hot and dry conditions but can still be present in other environmental conditions. Potential yield and quality loss from this disease are still unknown.

Disease Cycle

The disease cycle starts with the germination of fungal propagules. These fungal propagules, called microsclerotia, are present in soil or dead plant tissue and are stimulated by root exudates. The fungus can enter the canola root directly or through a wound in the root. The hyphae then multiply in the root and form conidia that move through the vascular system of the plant. The conidia establish new colonies in the xylem which inhibits the regular flow of nutrients and water in the plant, leading to wilting.

Figure 4.96 Life cycle diagram of Verticillium longisporum



Courtesy of: Canola Council of Canada

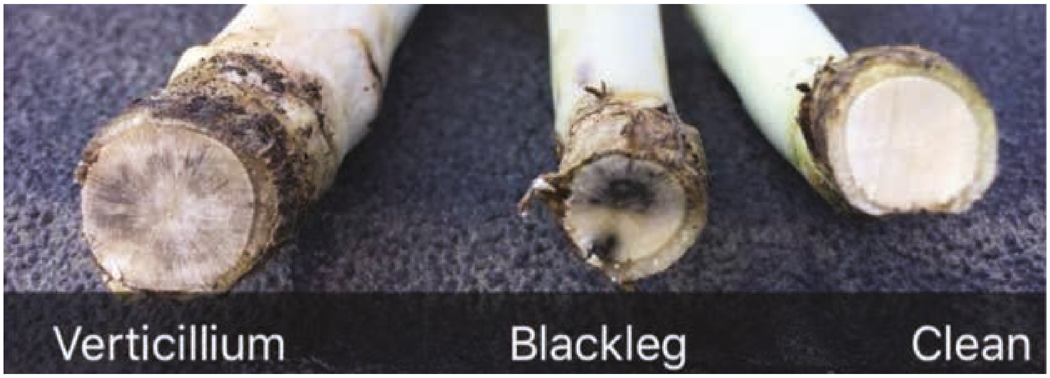
Symptoms and Scouting

Canola plants can display early symptoms of stem striping (partial senescence of half of the stem) and stem cross-section discolouration. As the disease progresses, the epidermis of the stem will begin to shred and peel away revealing tiny black dots underneath called microsclerotia. These microsclerotia are much smaller than the microsclerotia present in blackleg infections.

Table 4.4 Blackleg vs. Verticillium Stripe

Plant Disease	Blackleg	Blackleg	Verticillium Stripe
Species	Leptosphaeria maculans	Leptosphaeria biglobosa	Verticillium longisporum
Stem Symptoms and distinguishing features	Stem lesions with pycnidia (black spots) forming inside the lesion. Base of stem (crown) becomes woody. Cross section cut reveals blackening.	Shallow stem lesions with pycnidia	Shredding of the stem tissue. Tiny black microsclerotia form beneath the peeling outer layer.
Pod	No symptoms	No symptoms	No symptoms
Crown (base of stem) exterior	Cankering		
Crown cross-section	Solid black sections, often pie shaped. Fully black in extreme cases.	Typically does not reach stem in time	Greyish hue across entire cut. Gets darker as microsclerotia build up. Can extend many inches up the stem.
When to scout	Prior to swath timing, 60% seed coat change (SCC).	Prior to swath timing, 60% SCC	Easier to ID post-harvest
Yield loss	For every unit of increase in disease severity, a 17% loss in plant seed yield can be expected.	Comes in too late in the season to cause a significant impact	Does occur but no system to measure at this time.

Figure 4.97 Blackleg vs. Verticillium



Courtesy of: Canola Council of Canada

Management

Verticillium stripe management is complicated as there are limited options currently available. The best management strategy is crop rotation but microsclerotia can remain viable for multiple years. Microsclerotia are soil-borne so steps similar to clubroot control may be beneficial. There are currently no fungicides or soil amendments available for control of verticillium stripe.

Figure 4.98 Verticillium stripe, peeled back epidermis revealing microsclerotia

Figure 4.99 Stem shredding and microsclerotia on canola from verticillium stripe

Figure 4.100 Microsclerotia on canola from verticillium stripe

Fusarium Wilt

Fusarium oxysporum f. sp. *lini*

Fusarium wilt in flax is caused by the fungus *Fusarium oxysporum*. Fusarium wilt affects the plant's ability to take up water. Infected plants can be found scattered around the field, but they are generally found in patches. This disease is uncommon in Saskatchewan and is not a main disease of concern for flax.

Disease Cycle

Fusarium oxysporum survives as mycelium and spores in the soil and on crop residue. The fungus attacks the plant through the roots and grows through the plant into the xylem. This growth into the water-conducting tissue causes wilting. The disease can be spread by wind-blown soil, water runoff, or on infected seed.

Symptoms and Scouting

Symptoms can show up early and seedlings may be killed shortly after emergence. Later in the season symptoms appear as yellowing and wilting of leaves followed by browning and death of the plant. The tops of the plants at later stages of growth will often turn downward and form a "shepherd's crook".

Management

Crop rotation with a break of three years between flax crops is one of the best management strategies. The use of resistant cultivars and using registered seed treatments are additional control measures.

Figure 4.101 Classic shepherd's crook found on young plants infected with fusarium

Pasmo

Septoria linicola

Pasmo is a common disease found in flax in Saskatchewan and is caused by the fungus *Septoria linicola*. The disease prefers warm moist conditions and spores are dispersed by wind and rain. Pasmo impacts flax yield by causing defoliation and possible boll-drop if the infection is advanced. The earlier the infection the greater the potential for yield loss.

Disease Cycle

Pasmo overwinters as pycnidia on crop residue and flax seed. Infection usually starts from infected crop residue but can also originate from planting infected seed where the fungus spreads from the seed to the seedling. The pycnidia on old residue releases conidia that are spread by wind and rain and infect flax plants.

Symptoms and Scouting

The earliest symptoms are brown spots that appear on the leaves of flax. As the growing season continues these leaves fall off and eventually brown lesions will appear on the stems at the site where the leaf formerly was. These brown lesions expand and join to form bands that go around the stem. Plants with severe infection may turn completely brown and die.

Management

Pasmo can be carried on seed, so the first management strategy is to use clean seed free of disease. Another management strategy is using a crop rotation with at least 3 years between flax crops. Early seeding and balanced fertility can also aid in the reduction of pasmo.

Figure 4.102 Pasmo infection on stems and bolls

Figure 4.103 Pasmo infection on stem

Figure 4.104 Pasmo infection on flax stems

Sclerotinia

Sclerotinia sclerotiorum

Sclerotinia or white mould in sunflower is caused by the fungus *Sclerotinia sclerotiorum*. This fungus affects multiple broadleaf crops including canola, mustard and soybean. Sclerotinia can be devastating when sunflower crops are produced in regions where other broadleaf crops are common. The disease is very dependent upon environmental conditions and yield loss can vary significantly from year to year. There is potential to cause greater than 50 per cent yield loss with the right conditions. Sclerotinia symptoms can present in three different ways in sunflower; sclerotinia root rot, which includes basal stalk rot and wilt, sclerotinia stem rot and sclerotinia head rot including mid-stem rot.

Disease Cycle

Refer to Sclerotinia Stem Rot in Common Diseases of Canola and Mustard.

Symptoms and Scouting

Sclerotinia root rot, basal stalk rot

Sclerotinia root rot, basal stalk rot and wilt can cause sudden wilting during flowering. Tan coloured, water-soaked lesions develop at the base of infected plants. In some cases, the disease causes the stem to be girdled, and the plant will lodge. The stems become bleached looking and the tissue shreds.

Sclerotinia stem rot

Sclerotinia stem rot symptoms generally appear in the mid to late growing season as small water-soaked lesions near the soil line. Wilting of sunflower plants, bleaching of stems and shredding of the stem can occur.

Sclerotinia head rot

Sclerotinia head rot can occur before or after flowering. Lesions form on the backside of the head that are dark coloured and water-soaked. There can be white mycelial growth on the head. The inside of the head will rot and large sclerotia bodies can be found below the seed layer.

Management

The key to managing sclerotinia in sunflower production is planting into non-infested soil with limited sclerotia. Implementing a proper crop rotation including non-host crops can help reduce the risk of sclerotinia developing. Using wide-row spacings and wide-spacing between plants can help with plant-to-plant transmission.

Figure 4.105 Sclerotinia infected sunflower plant

Downy Mildew

Plasmopara halstedii

Downy mildew in sunflower is caused by an oomycete pathogen *Plasmopara halstedii*, which can be soil, seed and wind-borne. Symptoms of this disease can be evident at all growth stages and are more severe in cool moist growing conditions. Yield loss has the potential to be substantial but depends on several factors such as the percentage of infected plants, their distribution within the field and weather conditions.

Disease Cycle

The pathogen can survive in the soil for several years as oospores. These spores germinate under moist soil conditions and produce zoospores which can swim in the water in the soil to eventually infect the roots. Infection usually becomes systemic, and the pathogen asexually produces zoosporangiaphores on the lower leaves of the plant. Zoosporangiaphores release sporangia which can cause secondary infection. Oospores are sexually produced before the plant dies and permit the pathogen to overwinter and start the cycle over again when conditions are favourable.

Symptoms and Scouting

Seedling blight can occur when the plants become infected through the roots early in the season. Symptoms include thickened yellow leaves and dwarfed sunflowers. These plants are often not noticed, as they die shortly after emergence. Infection later in the season is called systemic infection. These plants can occur in large patches or singularly. In high humidity, the undersides of the leaves may be covered with white growth. Symptoms at this stage include stunting, yellowing and sometimes the development of a club-like root. Mature plants can produce normal-sized heads but generally contain empty seeds. Plants can also be infected by air-borne spores which cause angular leaf spots. This mode of infection causes small angular chlorotic spots on the leaves. These lesions rarely cause a systemic infection.

Management

Management strategies include seed treatments, avoiding seeding sunflowers into wet fields, and using hybrids that are resistant to downy mildew. Controlling susceptible weeds such as ragweed and wild sunflower are also useful to prevent the build-up of spores in alternate crop years.

Figure 4.106 Downy mildew on sunflower. Under surface of the leaf reveals white mycelium and spores of the disease.

Figure 4.107 Downy mildew on sunflower

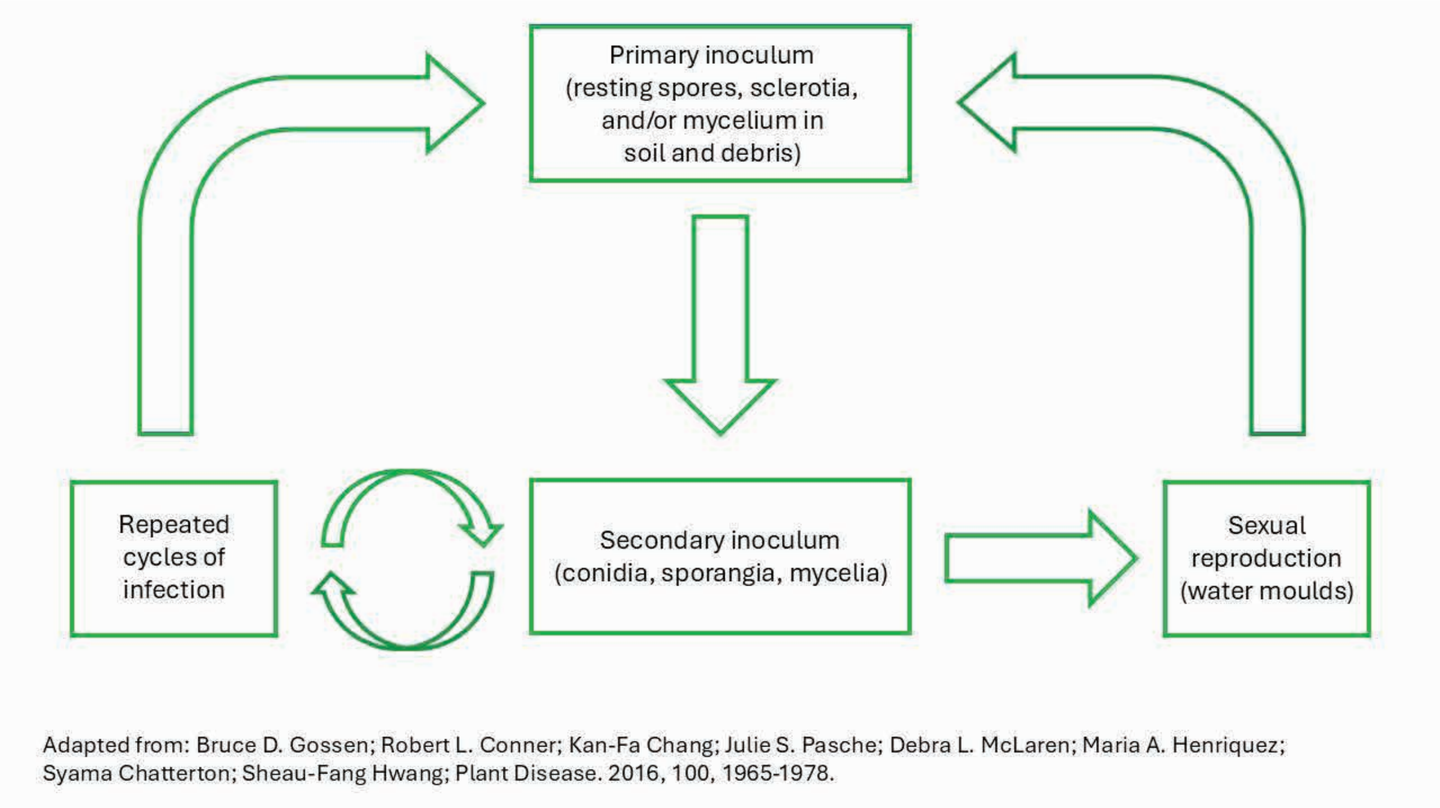
Root Rot Complex in Pulse Crops

Several pathogens can work together to cause a root rot complex in pulses and other crops. Disease severity is often related to environmental conditions. Most pathogens thrive in wet conditions except Rhizoctonia solani, which causes more damage in warm, dry soil conditions. Because several pathogens can infect plant roots and cause disease individually or at the same time as other pathogens, root rot in pulses is described as a complex. Identifying one specific species can be difficult; in some cases, confirmation is only possible with lab testing.

The one thing all pathogens that cause root rot have in common is the reduction of water and nutrient uptake through the roots which can limit growth and development in the entire plant.

The life cycle of all pathogens that cause root rot in pulses is similar.

Figure 4.108 A generalized life cycle for pulse root rots in the northern Great Plains of North America.



Primary inoculum in the soil begins to infect the host plant when seeds germinate or the root releases exudates. In time, the pathogen establishes itself in the host roots, and in doing so is able to complete its lifecycle. Inoculum is produced that can spread to healthy plants where infection and establishment repeat. Inoculum can also re-infect the host plant resulting in a secondary infection. Soil with diseased tissue can then be spread by wind, water, farm equipment and human activity.

The impacts of root rots include damping off, seedling blights, poor root growth, poor nodulation, root discolouration, leaf yellowing, stunting, and if later-season infections occur, crop lodging may be seen. These symptoms can all contribute to yield loss. The most severe symptom of root rots is death of the host plant.

For all root rot species in this section, genetic testing when available is the most reliable form of a definitive diagnosis.

Aphanomyces Root Rot

Aphanomyces euteiches

Aphanomyces root rot can be found across Saskatchewan. The disease is caused by an oomycete, or water mould, that is adapted to thrive in wet and waterlogged soils. Soil compaction, low water permeability, heavier texture and short rotations between susceptible crops can increase the severity of aphanomyces root rot. In wet years when infection is severe, yield loss can be up to 70 per cent. This disease can spread from an infected plant root to a healthy neighbouring plant 18 centimetres (seven inches) away. Root rot is most severe when infection occurs at the seedling stage, when the host is most susceptible to the pathogen and seedlings can be killed.

Pulse crops vary in susceptibility to aphanomyces root rot. Pea, lentil and cicer milkvetch are susceptible to this disease and if fields are infested, rotation to these crops should be delayed six to eight years. Dry bean and alfalfa are hosts, but some varieties are resistant. Faba bean, chickpea and sainfoin are resistant. Chickpea may act as a lure crop that activates oospores but prevents reproduction. Soybean and fenugreek are non-hosts.

Aphanomyces and fusarium root rot are often found together, and aphanomyces infection can be worse when other pathogens are present.

Disease Cycle

Aphanomyces is a soil-borne disease. Oospore infection of root tissue can occur at any stage of plant growth. Oospores germinate when they detect chemical signatures associated with host root growth and then infect the roots. This can happen either through hyphae from germinated oospores directly entering plant cells at the root tips or by mobile zoospores. These zoospores can swim through soil water films, toward the roots. When they reach the roots, the zoospore encysts, and hyphae are produced that infect the plant root. Once in the root, hyphae colonize the root tissues until the entire root system and below-ground stem are infected. The outermost layer of the root, the epidermis, may be completely destroyed by the pathogen. The pathogen can enter its sexual stage and produce oospores in as little as 10 days after first infecting the root. Oospores are thick-walled and can survive in their resting state for 10 to 15 years even when no host is present.

Symptoms and Scouting

To scout for aphanomyces and other root diseases, plants must be dug up to observe the main symptoms. Plant leaves and stems can still be green in the early stages of infection and spread. When root tissue decays, plants may look stunted, with leaves turning light green and then yellowing from the bottom of the plants up, as well as few pods and small seeds. When infection is later in the season, there may not be any above-ground plant symptoms. Symptoms on plants in the field are typically observed in low-lying areas, compacted areas such as tire tracks, and wet areas.

A distinguishing feature of aphanomyces root rot is caramel-coloured roots. After infection, the roots become slimy and turn grey with all infected roots eventually turning brown. Later in the season, the outer layers of the root tissue rot off leaving the vascular tissue. The tissue decay may extend up the stem slightly above the soil line. After roots are infected with aphanomyces, they are more prone to infection by other organisms in the soil and the tissue can turn black when other fungi colonize it.

If aphanomyces root rot is suspected, soil and/or root samples can be sent for DNA testing to determine soil spore load. Soil samples can also be sent away for bait testing, where aphanomyces-susceptible crops are grown in the soil to determine if oospores develop and what the spore load in that soil is. In almost all field conditions, the root rot pathogen causing the tissue damage cannot be confirmed by visual inspection in the field, even by researchers. Information on testing for aphanomyces and other root rot pathogens and which labs that do soil and/or plant analysis is available on the Saskatchewan Pulse Growers website or www.rootrot.ca.

Management

Once aphanomyces infects the root system, there is no way to stop its spread or reduce yield loss. The pathogen's oospores are persistent in soil, and currently, no method exists to manage them once they are present. While cleaning equipment during busy seasons is difficult, knocking off soil and avoiding field operations in wet conditions can reduce the risk of moving oospores. For equipment brought in from other areas, thorough cleaning is recommended before use.

The University of Saskatchewan offers an Aphanomyces Risk Evaluation App (AREA) to help assess field risks. The most effective long-term management strategy is crop rotation, with a minimum six-year break from pea and lentil crops, though a ten-year break may be required to lower spore counts. Additionally, controlling host weed species, keeping good crop records, and using seed treatments can help manage the disease.

Table 4.5 Aphanomyces Susceptibility Chart

Host Range Testing	
Crop	**Disease Reaction**
Pea	Susceptible
Lentil	Susceptible
Cicer milkvetch	Susceptible
Dry bean	Variable
Alfalfa	Variable
Chickpea	Resistant
Sainfoin	Resistant
Faba bean	Resistant
Soybean	Non-Host
Fenugreek	Non-Host

Figure 4.109 Aphanomyces spores

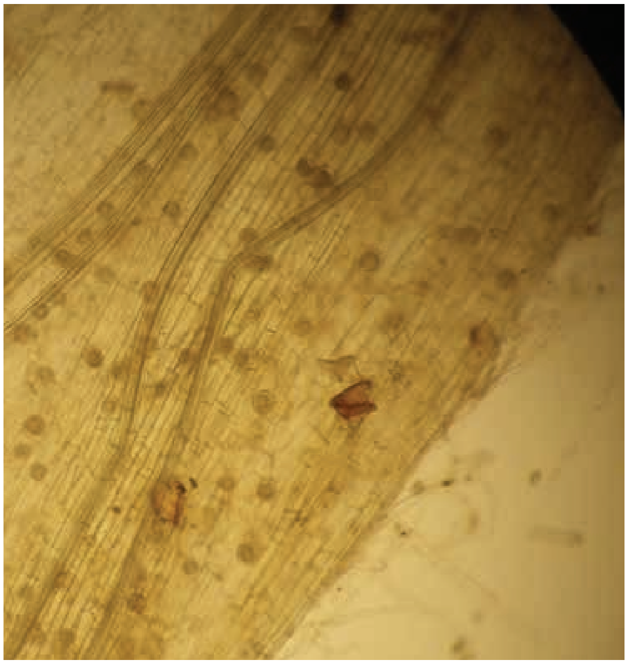


Figure 4.110 Aphanomyces on lentils

Courtesy of: AAFC

Figure 4.111 Healthy pea root system (left) compared to peas with aphanomyces (right)

Fusarium Root Rot

Fusarium spp.

Like aphanomyces, fusarium root rot infection can occur at any time during the plant's life cycle, and infection and development in seedling roots can cause plant death. Infections later in the season may not result in yield loss or above-ground symptoms.

Fusarium root rot is caused by a soil-borne fungi that can infect a wide range of crops, including pulses. Many species of fusarium that are widespread across Saskatchewan can cause root rot. The fusarium species that can cause root rot in pulses include (but are not limited to): *F. avenaceum, F. solani, F. redolens, F. oxysporum, F. graminearum* and *F. culmorum*. Recent research suggests that *F. avenaceum* and *F. solani* are the most aggressive fusarium root rot pathogens in peas in Saskatchewan and Alberta. *F. equiseti* and *F. poae* have also been found in pulses in the province. These non-specialized pathogens can also infect cereal crops, causing root rot and head blight.

Fusarium avenaceum has been the most frequently isolated pathogen in pea and lentil fields. On chickpea, *F. solani* and *F. redolens* has been the most common.

Cool, moist conditions are favourable for the early stages of infection. Later in the growing season, the combination of stress caused by the disease in the root and drought, soil compaction, low soil fertility and/or diseases on stem or leaf tissue can cause more significant damage than infection by the pathogen alone.

Fusarium root rot is commonly found with aphanomyces root rot.

Research has found that yield loss from fusarium root rot can be up to 60 per cent in pea fields and 84 per cent in dry bean fields.

Disease Cycle

Fusarium species that cause root rot can be seed-borne or soil-borne.

In the soil, fusarium spores germinate and produce mycelium which invade the plants below ground. If seed is damaged, the resulting seedling is more susceptible to infection. Fusarium root rot can start near the seed on the primary root and infect the cortex of the root. High soil moisture can cause the pathogen to produce conidia near the soil surface of the infected plant. When plant roots disintegrate, the fungus produces chlamydospores that are thick-walled and long-lived in most *Fusarium* species. *Fusarium avenaceum* is an exception because chlamydospores are not produced. Crop residue is a more important inoculum source for this species.

Symptoms and Scouting

Symptoms of fusarium root rot can be seen in low, wet, or compacted parts of the field alone or in combination with above-ground symptoms on individual plants. Reddening will extend up the root but is rarely seen in the stem above ground. External lesions are brick red, dark reddish brown, or chocolate coloured and spread up the stem and down the root. Infected plants become stunted, roots turn greyish then yellow, and lower leaves will wither and die.

As with aphanomyces, scouting for root rots involve digging up plants and looking at the roots to determine disease presence.

Management

Like aphanomyces, once roots are infected by fusarium and the disease has developed in the root system, no actions can prevent further spread and reduce the impact on yield as there is no way to manage them.

Because *Fusarium* species have such a wide host range, crop rotation is not very effective for this pathogen. Seed treatments are available for most crops and can prevent infection during the seedling stage when infection can cause plant death.

Figure 4.112 Red discolouration inside lentil root from fusarium root rot

Figure 4.113 Fusarium acuminatum

Figure 4.114 Fusarium on chickpea field

Figure 4.115 Fusarium on lentils

Figure 4.116 Fusarium infected pea field

Figure 4.117 Fusarium on lentil field

Figure 4.118 Fusarium stem lesion

Pythium Root Rot

Pythium spp.

Pythium is an oomycete plant pathogen, closely related to the pathogen that causes aphanomyces root rot. One species of pythium, *Pythium irregulare*, has been found worldwide and can infect over 200 host species of plants, including pulse crops. Yield loss can be as high as 50 per cent.

Some species of *Pythium* have a wide host range while others are very specific. They can be found in wet or moist environments, including soils, marshes and water. The greatest plant damage is seen when soils are waterlogged, and many mobile zoospores are made. Even one day of waterlogged soils can cause root infections. Some *Pythium* species may act as saprophytes.

Disease Cycle

Pythium forms resilient structures called oospores to overwinter. Oospores may remain dormant for several years of unfavourable conditions until favourable conditions permit germination. When there are more favourable conditions, the oospores can germinate and produce a germ tube that develops into hyphae in the root. A different pathway for infection is oospores germinating to produce sporangia that release zoospores, which can move in soil water. The zoospores encyst on host roots and form a germ tube into the plant.

See *Figure 4.108*

Symptoms and Scouting

As with other root rot diseases, symptoms are mainly below-ground. When pathogens infect seeds or seedlings before emergence, it can cause seedling blight. Post-emergence damping off occurs when the pathogen infects the seedling root and hypocotyl. Seedlings can survive root infection after emergence, but plants are less vigorous, and growth is reduced. Moderate to severe infection can make a field patchy. Infection when plants are more mature can still reduce plant growth and yield even when symptoms are not visible on the roots.

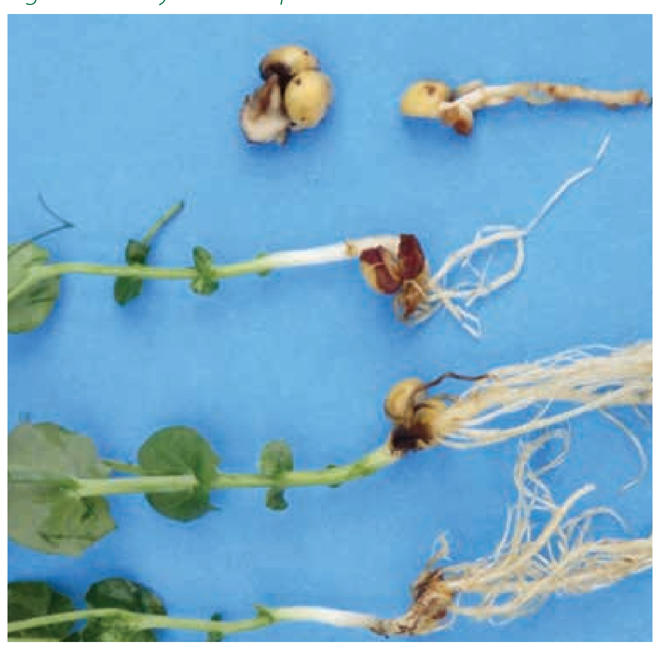
Management

Using a seed treatment can reduce the impact of *Pythium* for two to three weeks after seeding. Early seeding into cooler soils may allow seeds to germinate before warmer optimum temperatures for infection. *P. ultimum*'s optimum temperature for germination is 15 to 22.5 C. The optimum temperature for infection for *P. irregulare* is 17.5 to 27.5 C.

Figure 4.119 Pythium infection on roots

Courtesy of: L. Radmer University of Minnesota researcher

Figure 4.120 Pythium on peas



Rhizoctonia Root Rot

Rhizoctonia solani

Rhizoctonia solani is a soil-borne fungus with 14 groups that form separate hyphal networks that do not interact with each other. Three of these groups cause a reduction in seedling emergence and root rot in pulse crops in the northern Great Plains. They are AG-4, AG-2-2 and AG-2-1. Development of symptoms after infection is favoured by soil temperatures above 17.5 C. Hyphae spread is fastest from 24 to 30 C.

In inoculated trials, yield losses have been as high as 79 per cent in peas, 88 per cent in dry beans, 70 per cent in chickpeas, and 19 per cent in faba beans. Under field conditions, yield losses would likely be less, but these studies show the potential for high yield losses under ideal environmental conditions with lots of inoculum. Poor soil conditions, including compaction, low fertility and limited drainage will increase the risk of infection by *Rhizoctonia solani*.

Disease Cycle

The inoculum source for this pathogen can be hyphae in infected crop residue or sclerotia in the soil. Infected seed can also be a transmission source, but to a limited extent. Roots of plants can be infected and develop root rot at any stage of plant growth and development.

The pathogen is not known to reproduce asexually. Rather, the fungus survives unfavourable conditions as dormant sclerotia or melanized (darkened by a pigment) hyphae.

See *Figure 4.108*

Symptoms and Scouting

The impact of Rhizoctonia is below the soil surface and plants must be dug up to see major symptoms, while severe infections may produce above-ground symptoms.

Infection at the seedling stage commonly results in plant death via seed rot, damping-off and seedling blight. When infection occurs after the seedling stage, sunken reddish-brown lesions are seen on the roots and stem base. Soft rots have been observed on stems and roots in pea and faba bean. Reduced root nodulation can occur with severe symptoms.

Management

A few things can be done to reduce the impact of Rhizoctonia seedling infection and root rot. Seed treatments for Rhizoctonia are available that protect seedlings for the first two to three weeks after seeding but cannot protect plants from infection later in the growing season. Inoculation with rhizobia while seeding improves seedling health and can result in larger chickpea plants. Avoid deep seeding as it can cause stress to the developing seedling, reduce establishment and can increase root rot severity when the soil inoculum level is high. Compaction and the loss of organic matter can also increase severity. Reducing soil compaction improves the root and plant's ability to grow and can reduce root rot severity. Crop rotation to non-host cereal crops for at least three years can reduce the inoculum level in the soil but may not be the best for individual fields.

Table 4.6 Favourable Temperature and Environmental Factors for Different Root Diseases

Disease	Soil Temperature	Soil Moisture	Management
Fusarium complex	Wide range	Wet/dry	Not well defined
Rhizoctonia rot	Warm	Moist	Seed treatment
Pythium rot	Cool	Wet	Field drainage Seed treatment
Phytophthora rot	Warm	Wet	Field drainage Resistance Seed treatment

Adapted from: S. Banniza and S. Chatterton

Table 4.7 Root Rot Pathogens: Optimal Staging, Environment, Hosts, and Management

Pathogen	Stage Affected			Optimal Environment	Alternate Hosts	Management
	Seed Rot	Seedling Mortality	Root/Stem Decay			
Pythium spp.	●	●		Cold (10-15 C), wet soil	Pulses, cereals, canola, alfalfa	Seed treatment
Rhizoctonia solani		●	●	Warm (20-27 C), moist to wet soil	Pulses, cereals, canola, alfalfa	Seed treatment
Fusarium spp.		●	●	Warm (20-27 C), dry to moist soil	Pulses, cereals, canola, alfalfa	Seed treatment Partial resistance
Phytophthora sojae	●	●	●	Warm (20-27 C), wet soil	None	Resistance Seed treatment Crop rotation

Adapted from: S. Banniza and S. Chatterton

Figure 4.121 Rhizoctonia root and stem rot of soybean

Figure 4.122 Rhizoctonia infection on lentil

Figure 4.123 Soybean plants killed by rhizoctonia root rot

Courtesy of: D. Malvick, University of Minnesota

Figure 4.124 Rhizoctonia root and stem rot of soybean

Courtesy of: D. Malvick, University of Minnesota

Common Diseases of Chickpea

Ascochyta Blight

Ascochyta rabiei

Figure 4.125 Ascochyta blight lesions on chickpea

Ascochyta blight of chickpea is a fungal disease that affects the leaves, stems and pods. The disease is common in chickpea fields in the province and can require several in-season fungicide applications to prevent outbreaks when conditions are favourable. Rapid disease development occurs when there is warm (20 to 25 C), wet weather. If ascochyta spreads to the top of the canopy and wet conditions prevail, infection may lead to flower and pod abortion, resulting in significant yield loss (as much as 70 per cent). Lesions on pods can lead to infection, discolouration and shrinkage of the seed. Although several pulse crops can get ascochyta blight, each pulse crop has a specific *Ascochyta* species that causes disease.

Disease Cycle

The inoculum source for ascochyta blight is infected seed and crop residue. The disease is easily transmitted from seed to seedlings. Spores produced on crop residue can be sexually (ascospores) produced in pseudothecia, or asexually (conidia) produced in pycnidia. In the spring and during the growing season, released ascospores can travel several kilometres by wind. Conidia are spread by rain splash and may affect nearby plants in the growing season.

Under ideal conditions, the disease can progress from infection to visible symptoms in four days. On resistant varieties, dark brown pinprick lesions develop but do not progress. Lesions that produce pycnidia can release thousands of conidia within three to six days of forming.

Symptoms and Scouting

Symptoms first appear on lower leaves as light brown spots that often have dark brown margins. As the plant grows, lesions spread upwards. On stems, lesions are usually darker, and the margin is less obvious. Lesions can coalesce and become dotted with small, black fruiting bodies (pycnidia) that often develop in concentric circles. This expansion can girdle stems, causing them to break. Stems and leaves above that point die off. Circular patches of dead and dying plants are easy to see in fields with rapid disease development. Lesions on pods can result in discolouration, reduced seed quality and seeds that can act as an inoculum source.

Management

Ascochyta rabiei populations that are insensitive to Group 11 fungicides have previously been found in several chickpea fields in Saskatchewan. Because of this insensitivity, using fungicides with multiple modes of action that are effective on ascochyta and implementing fungicide group rotation is essential. Saskatchewan Pulse Growers has additional information online to assist with managing ascochyta blight in chickpea.

An integrated approach is the best way to manage ascochyta in chickpeas. Fields should be planted at least 500 metres away from chickpea stubble to prevent wind-blown spores from spreading the disease. Use a two-year waiting period before replanting chickpeas beside a field with chickpeas. Kabuli chickpeas should always have a seed treatment. Resistant varieties should be selected based on available resistance ratings in seed guides. Seed testing for ascochyta is essential, and seeds should ideally have zero per cent infection, with a strict limit of 0.3 per cent infection. Seeding rates should be carefully managed, as overly high rates can increase disease risk. Finally, rolling fields should be avoided after emergence to prevent plant damage and increased vulnerability to infection. (Saskatchewan Pulse Growers, 2024)

Figure 4.126 Ascochyta blight on chickpea leaflets

Sclerotinia Stem and Pod Rot (White Mould)

Sclerotinia sclerotiorum

Sclerotinia is caused by a fungus that can infect all broadleaf plants. Prolonged moist soil and cool environmental conditions can result in high disease levels. In chickpea, yield losses due to sclerotinia can be over 50 per cent if inoculum levels are high and the environment favours disease development. Quality may be a concern if sclerotia (hard, black, irregularly shaped bodies) are part of the harvested material and stay with the seed.

Disease Cycle

See Sclerotinia Stem Rot (White Mould) under Common Diseases of Canola and Mustard.

Symptoms and Scouting

Symptoms usually appear after canopy closure. Infection often starts on leaves or flowers and then spreads to girdle the stem or to infect pods and seeds. Water-soaked lesions will appear on stems, petioles, leaves, pods and seeds. Under wet conditions, lesions may be covered by fluffy white mycelium. In time sclerotia will form on the surface and inside the plant. Stems will become brittle and bleached, and foliage above the lesion dies leaving prematurely ripened plants scattered among healthy green plants.

Management

Due to the wide range of hosts, rotating to cereal crops is the most effective strategy for managing this disease. Several foliar fungicides are available to help manage this issue in chickpea. A few seed treatments are also available.

Figure 4.75 Sclerotinia on chickpea

Courtesy of: University of Saskatchewan

Common Diseases of Dry Bean

Anthracnose

Colletotrichum lindemuthianum
Colletotrichum truncatum

Anthracnose in dry bean is not usually a concern in Saskatchewan, but it can be serious in other parts of the world. It is seed- and residue-borne. Planting disease-free seed and a crop rotation with at least three years between bean crops can usually manage this disease. The fungus that causes anthracnose on dry beans is a different species than the fungus causing anthracnose on lentils.

Disease Cycle

The pathogen can survive in crop residue and seeds. Seed to seedling transmission is known to occur and results in seedlings that have cotyledons with disease symptoms including tan coloured lesions with dark margins. Spores that develop in these lesions are spread by rain, wind, and machinery. A disease outbreak may occur if frequent rainfall occurs as it enhances both the spread of the pathogen and provides optimal conditions for the infection process. Anthracnose symptoms can be present on various parts of the plant, including leaves, petioles, stems and pods.

Symptoms and Scouting

To scout for anthracnose in dry beans, turn over leaves of plants in low spots or where the crop has been planted adjacent to a field planted to beans the year before. Symptoms will include brown to purple lesions along veins of lower leaves, petioles and stems. Lesions on pods are circular with a brown centre and raised dark brown margin. Small black specs may be seen in the centres.

Management

To control anthracnose in dry beans, use disease-free seed and implement a crop rotation with at least three years between bean crops. Seed treatments and foliar fungicides targeting this disease are available.

Bacterial Blight

Xanthomonas axonopodis pv. *phaseoli* – Common bacterial blight
Pseudomonas syringae pv. *phaseolicola* – Halo blight
Pseudomonas syringae pv. *syringae* – Bacterial brown spot

Bacterial blights affecting dry bean are primarily seed-borne diseases and include halo blight, bacterial brown spot, and common blight . Although the leading cause of infection is diseased seed, the disease can overwinter on infected crop residue. Physical damage to plants such as hail damage will increase the risk of bacterial blight, especially if rainfall occurs after physical damage. Wet, windy weather can lead to significant infection. Halo blight is worse in cooler conditions, while common blight is favoured by warm weather. Plants infected with bacterial blight will have lower seed quality and yield. Yield losses of up to 45 per cent have been reported for susceptible varieties.

Disease Cycle

Infected plants grow from infected seeds. Growing cotyledons become coated in bacteria that can enter the plant's vascular system and spread or be splashed onto leaves and other parts of the same and other bean plants. The bacteria can also be spread by equipment in the field.

Symptoms and Scouting

<u>Bacterial brown spot</u>

The first symptom of bacterial brown spot appears as small water-soaked spots on the leaves. These spots develop into distinct, brown lesions with dead tissue, measuring approximately 3-8 mm in diameter, often surrounded by a narrow, diffuse yellow margin. As the disease progresses, these lesions may enlarge, merge, and fall out, resulting in a tattered appearance of the leaves. Additionally, sunken brown spots can form on the pods. If the infection occurs early in pod development, the pod may become bent or twisted at the site of infection.

<u>Common bacterial blight</u>

Leaf symptoms first appear as water-soaked spots that develop into irregularly shaped lesions with dead tissue that have bright yellow margins. These lesions can grow to 10 mm or larger and may kill the leaflets. Similar water-soaked spots can also form on the pods, enlarging into reddish-brown lesions. In humid conditions, a yellow bacterial exudate might be present on the pod lesions. Developing infected seeds may abort, shrivel, or discolour as they mature.

Halo blight

Halo blight symptoms begin as small, water-soaked spots on the underside of leaflets, which develop into reddish-brown lesions with greenish-yellow halos surrounding them. Severe infections can lead to yellowing and death of new foliage. At temperatures above 26 C, halos may be very small or absent. On pods, symptoms start as water-soaked spots and streaks that enlarge and may have a narrow reddish zone. Moist conditions can produce a light cream-coloured bacterial exudate on the lesions.

Management

The best control methods for managing this disease are planting clean, disease-free seed, having a two-year break between pulse crops in crop rotations and tilling infected residue to facilitate faster breakdown.

Figure 4.136 Bacterial blight on dry bean

Figure 4.137 Bacterial blight on dry bean

Common Mosaic Virus and Yellow Mosaic Virus

Dry bean seedlings can suffer from bean common mosaic virus or yellow mosaic virus.

Disease Cycle

The viruses are spread by insects such as aphids and can also be spread by planting infected seed. Yellow mosaic is not transmitted by seed but overwinters in perennial plants.

Symptoms and Scouting

Common mosaic virus symptoms include stunted and spindly plants, producing few pods and small, off-colour seeds. Leaves appear puckered and twisted.

Yellow mosaic virus symptoms include yellow spots on leaves and may come together to produce a loss of green colouration of leaves. Plants may become stunted with leaves appearing thick, cupped and brittle.

Management

Bean plant breeders have developed varieties that are resistant to several strains of viruses. Growers should use virus-free seed and control aphids when necessary to prevent possible infection.

Common Diseases of Faba Bean

Ascochyta Blight

Ascochyta fabae

Ascochyta blight is a seed-borne or residue-borne disease of faba beans in Western Canada. This is not the same ascochyta species that infects other pulses and is specific to faba beans. Cool, rainy weather is favourable for disease infection and spread. Ascochyta blight is most damaging to maturing pods and seeds if prolonged wet weather occurs during July and August. In severe infections, seeds developing in the pods become discoloured and shriveled. Severely infected seed lots may not be marketable or will be downgraded severely due to discolouration.

Disease Cycle

Refer to Ascochyta Blight under Common Diseases of Lentil.

Symptoms and Scouting

Lesions appear as tan or grey spots with dark margins on the leaves, stems and pods, and tiny black fruiting bodies (pycnidia) in the centre.

Management

Seed treatments and foliar fungicides are available. For other management strategies, refer to Ascochyta Blight under Common Diseases of Lentil.

Figure 4.138 Ascochyta blight on faba beans

Figure 4.139 Ascochyta blight on leaf

Bean Yellow Mosaic Virus (BYMV)

Bean yellow mosaic virus is the most common viral disease of faba bean. Infection before flowering can significantly reduce yields because it reduces nodulation. The vector for this virus is over 20 species of aphids, including pea aphids. There have been reports of seed transmission for this disease, but it does not commonly occur.

Disease Cycle

The virus is not seed-borne. It is transmitted to faba beans by aphids.

Symptoms and Scouting

Symptoms of BYMV include a characteristic mosaic pattern on leaves, with light and dark green areas. Affected leaves may also appear rolled or cupped, and necrotic leaf spotting can be present. Infected plants may show necrotic streaking on the stems, which can extend up to the shoot tip. In severe cases, the infection may cause the plants to die.

Management

Monitor aphid populations. There can be multiple growth stages of aphids in one season because of their short life cycle that occurs multiple times in a growing season. Because this disease is caused by a virus there are no seed treatments or foliar fungicides registered.

Figure 4.140 Bean yellow mosaic virus in faba bean

Courtesy of: Alberta Agriculture and Forestry & GRDC

Chocolate Spot

Botrytis fabae
Botrytis cinerea

Chocolate spot is a fungal disease that can impact faba beans as well as lentils in Saskatchewan and can sometimes be confused with alternaria leaf spot. *Botrytis cinerea* primarily targets lentils, causing what is known as botrytis stem and pod rot but can also infect faba beans causing chocolate spot. Research has shown that *B. fabae* generally causes more severe disease than *B. cinerea*, but continued work is being done to understand which pathogen is most problematic. The chocolate spot fungus thrives in 15 to 20 C temperatures and over 70 per cent humidity. Early disease onset will result in larger yield losses and will impact the quality of seed produced. Infections that occur mid to late in the season typically result in little to no yield loss.

Disease Cycle

Botrytis spp. can overwinter as sclerotia in soil, on crop debris, and on seed. Seed containing more than 10 per cent infection is not suitable for planting. Seed treatments can control seed-borne *Botrytis*. Spores are spread by wind and rain, requiring moisture for spore germination and infection; under warm, moist conditions, the disease spreads rapidly, with secondary infections occurring within four to five days of initial infection. Buckwheat and lentils are alternate hosts so crop rotation needs to be considered.

Symptoms and Scouting

Chocolate spot initially appears as small brown lesions on leaves, which expand and merge into larger brown areas under moist, warm conditions. After two to three weeks, these lesions turn gray and resemble botrytis or gray mold seen in other crops. In severely infected plants, sclerotia can be observed in the stems. Additionally, the disease causes dark, sunken lesions on the seeds. Chocolate spot lesions on lower leaves can be mistaken for herbicide, surfactant burn, or frost damage, as these also cause localized symptoms on specific leaves. However, these injuries do not spread beyond the initial damage, and similar symptoms may not appear on other plants, such as broadleaf weeds, within the field.

No predictive models or warning systems have been developed for Western Canada.

Management

To manage chocolate spot, choose new faba bean varieties and plant clean, disease-free seed. Economic thresholds for chocolate spot in faba beans have not been established, but research is underway regarding fungicide response and the effects of application timing. Seed treatments and foliar fungicides are registered for chocolate spot.

Figure 4.141 Chocolate spot faba bean leaf

Figure 4.142 Chocolate spot on faba beans

Sclerotinia Stem Rot (White Mould)

Sclerotinia sclerotiorum

Sclerotinia diseases are widespread throughout Canada and are favoured by moist conditions and dense crop canopies, causing damage to crops in the field and storage. In Saskatchewan, this fungal disease is less common in faba bean than in other broadleaf crops such as canola. However, if conditions are suitable for disease development, it can impact faba bean crops.

Disease Cycle

Refer to Sclerotinia Stem Rot (White Mould) under Common Diseases of Canola and Mustard.

Symptoms and Scouting

The disease initially appears on the stem near the soil surface as a water-soaked area that gradually spreads upward and downward. The affected region becomes bleached and eventually turns light brown. When the stems are split open, they reveal a characteristic white fungal growth, with numerous black, hard resting bodies (sclerotia) in the pith. Sclerotia germinate to produce tiny, golf tee-shaped structures called apothecia, which then disseminate spores that can infect healthy plants. As the disease progresses, affected plants often experience poor yield and may die prematurely.

Management

Crop rotation is an important strategy for preventing disease, with a recommended interval of three to four years between planting faba beans and other host crops. When planting faba beans, following a cereal crop rather than an oilseed or pulse crop is suggested. Registered foliar fungicides for sclerotinia stem rot should be applied before symptoms appear. Once symptoms are apparent, it is too late to effectively apply fungicide because sclerotinia only has one disease cycle per year (monocyclic).

Figure 4.143 Sclerotinia stem rot on faba bean

Courtesy of: Alberta Agriculture and Forestry

Stemphylium Blight

Stemphylium spp.

Stemphylium blight used to be considered a minor issue in Saskatchewan, however, this fungal disease has quickly become widespread. The visual symptoms can be confused with those of chocolate spot. Potential yield loss estimates are still being researched.

Disease Cycle

Refer to Stemphylium Blight under Common Diseases of Lentil.

Symptoms and Scouting

The first symptom is small, water-soaked spots that appear on the surface of the leaves. These spots eventually develop into blackish-brown lesions. As the lesions grow, they spread over the leaf veins and merge, causing the leaves to wither. As the disease progresses, it leads to leaf defoliation and possible plant death. Stemphylium blight symptoms are not known to spread to flowers or pods of faba beans.

Scouting should continue past flowering since symptoms appear later in the season compared to other blights and are more common during growing seasons with high levels of precipitation.

Management

Currently, no fungicides are registered to treat stemphylium blight in faba bean in Saskatchewan, so cultural control is important. Growers should take field proximity into account when planning faba bean rotations and avoid planting too close to fields planted with faba beans in the previous year. A crop rotation of at least 4–5 years between faba bean and lentil crops is strongly recommended to help minimize risk.

Figure 4.144 Stemphylium blight

Courtesy of: Alberta Agriculture and Forestry & GRDC

Common Diseases of Field Pea

Ascochyta/Mycosphaerella Blight Complex and Ascochyta Foot Rot

Didymella pinodes - Ascochyta/Mycosphaerella blight
Phoma medicaginis var. *pinodella* - Ascochyta foot rot
Ascochyta pisi – Ascochyta blight

Mycosphaerella blight is the most common disease of pea in Western Canada. Symptoms on the stem are hard to differentiate from ascochyta foot rot so the two diseases have been combined. In cool, wet conditions, these fungi can cause severe levels of disease in the field.

Disease Cycle

Pathogens are seed-, soil- and stubble-borne and can survive in the seed for several years or as resting spores in the soil. Emerging seedlings that contact resting spores or the pathogen growing from the seed into the stem cause infection. In the spring on residue on the soil surface, ascospores (sexual spores) of *Mycosphaerella pinodes* are produced. These spores can spread long distances by wind and cause infection in all above-ground parts of plants. Diseased leaves and lower stems produce ascospores during the growing season. Both pathogens also develop asexual spores (conidia) that spread over short distances by rain splash.

Symptoms and Scouting

The pathogens cause lesions on leaves, stems, flowers and pods. Ascochyta foot rot causes foot rot symptoms at the stem base. Early mycosphaerella infection on leaves causes small, purplish lesions with irregular, indefinite edges. When conditions are moist or on older leaves, the lesions get bigger and can join, causing the plant tissue to dry up. On petals, lesions are small but may cause the infected flower to drop. On stems, lesions are purplish-black and often join to cause extensive blight and foot rot. On pods, lesions start small and are lighter when the disease is ascochyta/mycosphaerella blight than when the disease is ascochyta foot rot. On ripe pods, lesions may expand into large areas of purplish-brown. Seeds in infected pods may be shrunken and discoloured or show no symptoms. Seedlings that germinate from infected seed often have disease symptoms, but they are only on the stem base where the cotyledons attach to the stem. Scout for these diseases from mid-June to the end of July.

Management

Peas should be grown in a field no more than once every four years to manage these diseases. Using disease-free seed can also reduce crop loss. A pea field should be planted as far away as possible from the previous year's pea fields. Seed treatments may prevent the disease from being introduced to new areas where peas have not been commonly grown. Fungicide seed treatments can reduce the impact of other seed-borne diseases. Foliar fungicides are available for in-crop applications.

Figure 4.145 Ascochyta on pea leaves

Courtesy of: University of Saskatchewan

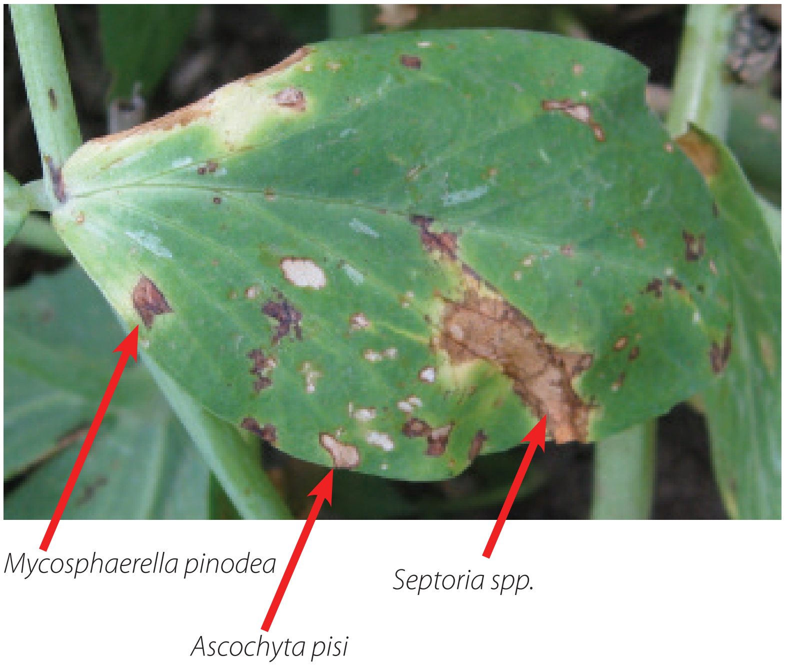
Figure 4.146 Ascochyta on stipules

Courtesy of: AAFC

Figure 4.147 Ascochyta pisi lesions with pycnidia on pod

Figure 4.148 Mycosphaerella blight in peas

Figure 4.149 Distinct symptoms of mycospharella/ ascochyta / septoria on the same leaf on field pea



Courtesy of: Sabine Banniza, University of Saskatchewan

Downy Mildew

Peronospora viciae

This disease is common in Saskatchewan but is not as economically important as other pulse diseases. Fungus-like (oomycete) organisms cause downy mildew. This disease mainly affects peas but can also be found in other field crops such as canola. Environmental conditions that favour the disease development are lower temperatures and moist conditions including fog. Severe downy mildew infection can cause sterile flowers and can impact the number of pods set, seed size, seed quality and yield.

Symptoms

A fluffy greyish growth develops in patches on the undersides of leaves, potentially covering the entire underside, and can spread to the upper part of the leaf, stem and pods in more severe cases. Systemic infection leads to severe stunting, foliar distortion, and seedling death. The top of the leaf becomes yellow and brown opposite to the infected area on the underside. Pod infection causes seed abortion and discolouration. Scout for downy mildew from mid-June to the end of July.

Disease Cycle

Infection comes from inoculum in the soil or seed. During the growing season, fungal mycelia grow after exposure to moisture and develop sporangia that can spread the disease from plant to plant by wind or rain splash. The pathogen survives in the soil and seed and may also be carried over on infected crop residue. Oospores have been shown to survive in soil for 10-15 years.

Management

To decrease soil-borne inoculum, a two or three-year crop rotation is recommended. Seed sourced from an area of lower rainfall will produce cleaner seed, usually free of seed-borne inoculum. A few seed treatments are available. Several fungicides are registered for suppression, but no fungicides currently exist for control.

Figure 4.150 Downy mildew on pea leaves

Figure 4.151 Downy mildew damage on pea

Figure 4.152 Beginning stages of downy mildew on pea

Figure 4.153 Downy mildew on pea

Pink Seed

Erwinia rhapontici


Figure 4.154 Pink pea in field peas

Pink seed in field peas has been found in isolated cases in Saskatchewan. It is caused by an opportunistic bacterial plant pathogen that can infect peas, beans, chickpeas, faba beans, wheat, durum, and many other crops. Incidence of pink seed increases in seasons with above-normal precipitation. The bright colouring on the seed can sometimes be confused with seed treatments. Pink seed, when present in high enough quantities, can downgrade seed samples based on the "Peas of other Colours" grade determinant. The disease can also impact seed size, and viability when used as seed.

Symptoms and Scouting

Infected seed will be shriveled and turn an intense pink or red colour, similar to seed treatments, but the colour will not wash off with water. Symptoms on yellow peas are more noticeable due to the contrast in colour. There are no in-season scouting techniques that will help in the prevention of the disease.

Disease Cycle

Erwinia rhapontici infects plants through wounds caused by insect feeding, wind, or hail damage. Research has shown that damage during pod development results in a higher rate of seed infection. This bacterial pathogen can overwinter on seed and on infected crop residue.

Management

The best control method is to use clean, certified seed, as research has shown that planting infected seed resulted in an average of 33 per cent reduction in plant emergence. Fungicidal seed treatments are not effective since the disease is caused by bacteria rather than a fungal pathogen.

Powdery Mildew

Erysiphe pisi

Once widespread in Western Canada, powdery mildew is now rarely of significance since most pea varieties grown are resistant to the disease. This fungal disease is most evident in susceptible varieties when the crop is seeded late or is a late-maturing variety. Powdery mildew thrives under warm, dry daytime conditions and cool, dewy nights with limited rainfall. This disease is easier to see on late-seeded or late-maturing crops. More than 60 per cent yield loss has been reported in susceptible varieties. Peas are the primary host for this disease.

Symptoms

Symptoms appear as fine, powdery white spots on the upper surface of leaves that spread rapidly over the entire surface of leaves, stems, and pods. The plant tissue below the mildew may show a purplish discolouration. As the plant ages, pinhead-size sexual fruiting bodies (cleistothecia) develop on the infected tissue. They start out golden-brown and then become black at maturity. Scout for powdery mildew mid-July to late August.

Figure 4.155 Powdery mildew on peas

Disease Cycle

Since it has not been established that overwintering cleistothecia contain viable ascospores in Saskatchewan, initial infection is a result of long-distance transport of conidia from the southern part of the continent. These conidia develop in the mildew on the leaf surface from the first lesions on the plant and cause rapid secondary spread. As summer progresses, disease level increases.

Management

Crop rotation is of limited value due to the wind-blown spores. Growing a resistant variety is the best way to protect against powdery mildew. New pea varieties registered in Canada for production in Western Canada must have powdery mildew resistance. Multiple fungicides are registered for the control of powdery mildew in field pea.

Rust

Uromyces fabae

Rust in peas is rare in Saskatchewan but does occasionally occur. Rust is a fungal disease that mainly affects the vegetative structures of the plant. The disease favours warm humid weather for development. It can affect different field crops in Saskatchewan including dry bean. Rust is not significant enough to pose a risk to yield or quality loss to field pea in Saskatchewan.

Disease Cycle

The fungus overwinters as teliospores on crop residue. In spring these teliospores produce basidiospores that are wind-blown to pea leaves. Infection leads to the production of specialized fruiting bodies (pycnia and aecia), which are rare and not noticeable in the field. Aecia produce aeciospores, which infect plant leaves. This leads to the production of urediniospores, which can be carried long distances to produce new infections. Severe infection results from the completion of multiple generations of urediniospores, with teliospores developing in late summer.

Symptoms and Scouting

Initial symptoms appear as small, whitish, slightly raised spots. These enlarge and rupture the epidermis to produce reddish-brown, irregular pustules on the stems, pods, and lower surfaces of leaves. Pustules initially contain abundant, powdery urediniospores, but eventually turn dark brown to black when overwintering teliospores are produced.

Management

Rotating crops and plowing under crop residue will reduce the number of spores that survive through the winter. Registered propiconazole fungicides may be used for controlling rust if the disease develops.

Figure 4.156 Rust infected pea plants

Figure 4.157 Rust pustules on underside of pea stipule

Sclerotinia Stem Rot (White Mould)

Sclerotinia sclerotiorum

Sclerotinia has a wide host range in Saskatchewan and was formerly a serious problem in peas when heavy crops lodged. In the new dwarf semi-leafless pea varieties, this fungal disease is much less of a problem but can still be present especially when grown in a rotation following canola. Warm, humid, and moist environmental conditions help the onset of this disease. Seed quality can be impacted by reducing germination and seed size.

Disease Cycle

Refer to Sclerotinia Stem Rot (White Mould) under Common Diseases of Canola and Mustard.

Symptoms and Scouting

Sclerotinia stem rot in field peas causes soft rot of the leaves, stems, and pods within the canopy. Under humid conditions, a fluffy white mycelium becomes visible on the surface of the rotting tissue. Infected stems may wilt or ripen prematurely. In dry conditions, the affected areas appear bleached and become easily shredded. Sclerotia bodies, which are the hard, black resting structures of the fungus, can be found both on and inside the infected stems and pods.

Scouting should begin while there is space between rows so that if a fungicide application is warranted, it can be done before canopy closure. Scouting at the end of the growing season is also recommended to help with management decisions and crop planning for consecutive years.

Management

Manage sclerotinia in peas by including non-host crops in rotation like cereals. If the disease is severe, spread rotation out of susceptible crops for four or more years. Choose semi-leafless pea varieties to grow to allow more airflow between plants. Seed treatments are available for this disease in peas. Fungicide applications must be done before symptoms are noted, otherwise, it is too late and ineffective.

Figure 4.158 Sclerotinia stem rot in field pea

Septoria Leaf Blotch

Septoria pisi

Septoria leaf blotch is a fungal disease that favours warm weather and long periods of high humidity. This disease rarely causes significant economic damage in peas since it primarily attacks older leaves. There are many strains of *Septoria spp.* that cause disease in other crops, *Septoria pisi* mainly affects peas in Saskatchewan.

Disease Cycle

The disease cycle for septoria leaf blotch starts with fungal spores being released from diseased crop residue. After leaves are infected, spores can also be released from leaf lesions, especially in humid weather. Spores can spread with the wind to infect new crops, especially when a tight pea rotation is followed. Rain splash can spread the disease within the crop, creating secondary infections. Although this disease can be transmitted on the seed, it is of minor importance.

Figure 4.159 Septoria leaf blotch on peas

Symptoms and Scouting

Symptoms of septoria leaf blotch in peas will show up mostly on older leaves. As the disease develops, yellow blotches on leaves become straw-coloured with a lighter centre. When the disease is established, lesions become speckled with dark brown pycnidia and can have dark, concentric markings with an undefined yellow halo.

Management

An extended crop rotation is the most effective for septoria leaf blotch in pea since the fungus survives on crop debris.

Common Diseases of Lentil

Anthracnose

Colletotrichum truncatum
Colletotrichum lentis

Anthracnose is a fungal disease that thrives in warm, wet conditions and worsens when crop rotations are short. It can affect dry bean, soybean and lentil crops. Anthracnose can cause over 50 per cent yield losses due to its ability to girdle stems, causing leaf drop, wilting, and ultimately plant death. Some lentil varieties are resistant to the anthracnose race Ct1, but no varieties are resistant to the dominant race Ct0 found in the prairies.

Disease Cycle

Anthracnose overwinters in fields as microsclerotia on crop residue, which can remain viable in the soil for up to three years if buried. If they are not buried and are exposed on the soil surface, they have a much lower viability. Microsclerotia are splashed by rain onto lower leaves and stems of plants and initiate infection. Spores (conidia) will be produced within these infection sites and will spread the disease through the canopy by rain splash. The pathogen can spread to neighboring fields through wind or the mechanical movement of debris. Rain splash during the growing season also can also spread disease. Seed-borne transmission of the disease is also possible.

Symptoms and Scouting

Initially, white to grey, oval lesions develop on the lower leaflets and spread upward. Early symptoms sometimes appear at the seedling stage but more commonly occur when the crop canopy begins to close. As the disease progresses, lesions become tan and margins darken, and the affected leaflets eventually fall. Stem lesions are also tan to brown, sunken, and typically start near the stem base and spread vertically and horizontally. These lesions can girdle the stem, leading to plant death. The stems of plants killed by anthracnose often exhibit a blackened appearance due to the formation of tiny, black microsclerotia, which persists on the stubble after harvest. These resting bodies, visible under magnification, are irregular in shape, smaller, more numerous, and more closely clustered than the pycnidia of ascochyta. Yellow patches are often visible in fields after the canopy closes. These patches enlarge as the disease spreads and plants in the centre start dying and turning dark brown.

Fungicide decision support charts can help decide if a fungicide application is warranted, and an example is below. The table requires crop scouting between the 10th node stage and early flowering. A risk value is then calculated based on the risk factors listed. If the risk value is less than 50, a fungicide application is not recommended, but a new assessment should be made at three-to-five-day intervals until the crop is no longer flowering. A fungicide application is recommended when the risk value is 50 or above.

Table 4.8 Fungicide Application Support Tool for Anthracnose in Lentil

Factor	Risk Estimation					Scores					
						1	2	3	4	5	Average
Plant Stand	Thin (0)	Moderate (5)	Normal (10)	Dense (15)	-						
Rain in the Last 14 Days	None (0)	1-2 days (5)	3-4 days (10)	5-6 days (15)	7+ days (20)						
5-Day Weather Forecast	Dry (0)	Unpredictable (10)	Showers (15)	Rain (20)	-						
Symptoms on Plant	None (0)	Few lesions on lower 1/2 up to 10% infected (5)	Lesions on lower 1/2 up to 25% infected (15)	Lesions + premature leaf drop (Anthracnose) (25)	Lesions at stem base (30)						
Score	*If 50 or more, then fungicide application is recommended*										

Courtesy of: SaskPulse
Source: Developed by Lone Buchwaldt, Godfrey Chongo, and Bruce Gossen, with Agriculture and Agri-Food Canada.

Management

Proactive management strategies for anthracnose in lentil include a four-year crop rotation, with a three-year break between lentil crops. Managing residues so plant material breaks down quickly will help reduce spore load. Moderate resistance is available with certain seed varieties. Seed can be tested for the presence of disease prior to planting. A fungicidal seed treatment will also help protect against infection. Scout fields during the season and ensure there is justification for applying in-crop fungicides.

Figure 4.160 Anthracnose on lentil

Figure 4.161 Anthracnose on lentil stem

Figure 4.162 Anthracnose lesion with microsclerotia on lentil stem

Figure 4.163 Anthracnose lesions on lentil

Figure 4.164 Anthracnose diseased field

Ascochyta Blight

Ascochyta lentis

Ascochyta blight is a fungal disease found in lentils in Saskatchewan, although most varieties are resistant. This is not the same ascochyta species that infects other pulses and is specific to lentils. Lesions from the disease can cause flower and pod abortion and are the main cause of yield loss. During severe outbreaks in susceptible varieties, yield loss can be as high as 40 to 50 per cent. Field pea and chickpea are not hosts of ascochyta blight and therefore, can be included in a crop rotation without stimulating the disease more.

Disease Cycle

The fungal spores overwinter on infected crop residue but do not survive in soil. Spores located on crop residue can be spread to neighboring fields by the wind. Within fields, rain splash becomes the main source of spread. Infected plants will spread the disease to the seed and if the late summer weather conditions are wet, extensive pod and seed infection will occur.

Symptoms and Scouting

Symptoms of ascochyta blight in lentils start with spot-like lesions, which are initially light grey and become tan with a darker brown margin. Lesions will be found on leaflets, petioles, stems, peduncles and pods. Pod lesions are usually darker than those on other structures. Peduncle lesions cause flower and pod abortion and are the major cause of yield loss. Centres of lesions become speckled with pycnidia, similar to septoria, but septoria lesions contain concentric markings and are mainly confined to lower leaflets. Later infection will cause leaf drop and stem dieback, giving the crop a brown blighted appearance. Pod infection may lead to seed infection and discolouration.

Management

Many lentil varieties have moderate resistance to ascochyta blight. Some varieties have intermediate resistance. When these varieties are grown, the resistance significantly reduces the risk of ascochyta blight. Agronomic and cultural management methods include growing lentils only once in a three-year rotation, not planting lentils beside a field with lentil residue, planting clean, disease-free seed, using a seed treatment, scouting fields and a fungicide application if it is needed.

Figure 4.165 Ascochyta-infected lentil

Figure 4.166 Ascochyta-infected lentil

Botrytis Stem and Pod Rot (Grey Mould)

Botrytis cinerea

Botrytis cinerea is a fungal pathogen that infects many species including lentils. Botrytis grey mould causes stem and pod rot during flowering and seed- filling stages and can cause economic losses. Lentil seed can become discoloured and shriveled potentially causing downgrading. Soil-borne inoculum is present in all fields, but the disease is typically only a problem in heavy vegetative stands that are lodged and when there are wet, cool environmental conditions.

Disease Cycle

The pathogen is both seed- and stubble-borne. Seedling blight develops when seeds are infected or when crop residue from a previous season is heavily infested. *Botrytis cinerea* is a common pathogen that can infect a wide range of plant species. It is also a prolific saprophyte that can be present on mature lentil plants without those plants having an infection at the seedling stage.

Symptoms and Scouting

Premature ripening of plants can occur due to infection of the lower stems, with affected areas turning light brown or bleached and covered in a grey, mouldy growth. Pod lesions commonly form at sites where dead petals come into contact with the plant, as botrytis tends to colonize dead plant tissue first. Infected pods become brown, rotten, and covered in grey mould. The seeds within those pods may appear shriveled and discoloured. In dense, lodged stands, the disease often develops in patches, spreading from plant to plant.

Start scouting for botrytis stem and pod rot at the eight to 10 node stage. When scouting, look for signs of premature ripening and the characteristic grey, mouldy growth on stems and pods. Disturbing heavily infested tissue will cause clouds of grey spores to rise from the mould.

Management

Use clean disease-free seed and treat with a seed treatment. Preventative in-crop fungicide applications may be done; follow label recommendations for proper application timing.

Figure 4.167 Botrytis stem and pod rot in lentil

Courtesy of: Cheryl Cho

Figure 4.168 Botrytis stem and pod rot in lentil

Sclerotinia Stem and Pod Rot (White Mould)

Sclerotinia sclerotiorum

Sclerotinia is a fungal disease in Saskatchewan that has a wide host range. This disease can impact lentils with dense stands but otherwise is not usually a major cause for loss. Inoculum levels have been increasing due to the higher number of crops in a crop rotation that are susceptible to the disease. Other hosts for this pathogen include field pea, faba bean, soybean, chickpea, canola, mustard and all broadleaf weeds. Yield losses from sclerotinia in lentil can be greater than 50 per cent if inoculum levels are high and the environment favours disease development. Rainfall and high soil moisture create favourable conditions for sclerotinia germination and spore production. Crops are more susceptible to sclerotinia stem and pod rot when it rains after the crop canopy has closed as this will create a humid environment in the crop canopy that favours sclerotia germination.

Disease Cycle

Refer to Sclerotinia Stem Rot (White Mould) under Common Diseases of Canola and Mustard.

Symptoms and Scouting

Symptoms of sclerotinia in lentil include wilting, stem infection and bleaching of tissues. The presence of white mould and black sclerotia (resting bodies) are similar to symptoms on field pea. Unlike canola, sclerotia bodies form outside of the plant, initially looking like white balls that will dry down and blacken. In dense, lodged stands, the disease develops in patches due to plant-to-plant spread. When scouting, lift plants up and look underneath the canopy where the mould will be apparent. Begin scouting for sclerotinia in lentil when the canopy fills in and weather conditions are conducive to disease development.

Management

Manage sclerotinia in lentil by including non-host crops in rotation like cereals. If the disease is severe, rotate out of susceptible crops for four or more years in that field if possible. Wide row spacing and lower seeding rates may decrease infection due to improved canopy ventilation. Fungicide application should be done as a preventative measure since the disease is monocyclic and spraying once symptoms have developed is ineffective.

Figure 4.169 White mycelial growth on lentil stems and leaves caused by Sclerotinia sclerotiorum.

Figure 4.170 Sclerotinia sclerotiorum infection on lentil leaves

Stemphylium Blight

Stemphylium botryosum
Stemphylium spp.

Stemphylium blight is a fungal disease and a saprophyte in nature. It is common in lentil and other legumes. Stemphylium prefers warm temperatures above 25 C and a minimum of eight hours of leaf wetness for optimal disease development. Significant yield loss has not yet been confirmed because the disease tends to show up later in the growing season.

Figure 4.171 Stemphylium blight infected lentil leaves

Figure 4.172 Stemphylium blight on lentils

Disease Cycle

The fungal infection spreads mainly on infected seed and crop residue. Spread within the field occurs when airborne fungal bodies, known as conidia, land on leaf surfaces and infect them. The pathogen overwinters on crop residue and can survive on seed.

Symptoms and Scouting

Symptoms of stemphylium blight in lentil appear initially as small, light-beige lesions on leaves/leaflets on the upper part of the plants. Lesions can appear at all stages of crop development. Small lesions coalesce to produce large, irregularly shaped lesions that kill entire branches.

Management

Since the pathogen is a saprophyte, crop rotation is likely not to have a large impact on control. Choose seed free of disease in the spring. Fungicides that are used to control ascochyta blight or anthracnose may also reduce stemphylium blight. A crop rotation of at least 4–5 years between faba bean and lentil crops is strongly recommended to help minimize risk.

Common Diseases of Soybean

Anthracnose

Colletotrichum truncatum

Anthracnose in soybean is caused by a fungus found in infected seeds and on infected crop residue. Infected seeds may have brown or grey areas with black spots or exhibit no symptoms at all. This pathogen also infects lentils and dry beans. Yield loss from this disease is usually minimal because infection in soybean happens later in the growing season. Anthracnose is not typically a significant issue for soybeans in Saskatchewan.

Figure 4.173 Anthracnose on soybeans

Disease Cycle

Refer to Anthracnose under Common Diseases of Lentil.

Symptoms and Scouting

When infection occurs at the seedling stage damping off may occur from sunken cankers on the cotyledon, epicotyl and radicle. Infected leaves will develop chlorotic areas and brown veins and will curl up. Brown cankers can be found on petioles. Symptoms on stems and pods are irregular brown spots. If affected areas are viewed at 10 times magnification, tiny black spines, called setae, will be visible.

Management

Seed testing is available for this disease and can give an indication of presence. Use a crop rotation with a three-year break between susceptible crops when there is a high spore load. Managing residue so plant material breaks down quickly will help reduce the impact of crop residue on disease levels. A few fungicides are available for anthracnose in soybean.

Figure 4.174 Anthracnose on soybeans with stem lesions

Bacterial Blight

Pseudomonas savastanoi pv. *glycinea*

Bacterial blight is a bacterial disease found in all soybean-growing areas. The disease rarely causes yield loss, but it occasionally causes defoliation. Cool, wet weather favours disease development.

Disease Cycle

Contaminated crop residue and infected seed are how this disease is carried from one season to the next. In-season spread will occur by wind and rain. Early lesions can produce inoculum for secondary infection.

Figure 4.175 Bacterial blight infected leaves on soybean

Symptoms and Scouting

Symptoms of bacterial blight will first be observed in the upper canopy as young leaves are more susceptible. Small, water-soaked, and angular leaf lesions can be present on leaves, stems and petioles. Lesion centres will turn brown and are surrounded by a bright yellow halo. Dead tissue in older lesions will fall out giving leaves a tattered appearance similar to hail damage.

Management

To manage bacterial blight in soybeans, use disease-free seeds and select resistant varieties. Incorporate non-host crops in your crop rotation. Fungicide applications will not be effective since it is a bacterial disease and not a fungal disease.

Downy Mildew

Peronospora manshurica

Figure 4.176 Early sign of downy mildew infection on soybean leaf

Figure 4.177 Light green spots caused by downy mildew infection on soybean

Downy mildew is a disease affecting soybeans. Although the disease can be seen on plants, yield reductions only occur in rare circumstances. Seeds can become covered with fungus causing quality concerns. Environmental conditions that favour disease development and spread are cool, wet or humid weather. Downy mildew in pea is caused by a different *Perenospora* species.

Disease Cycle

Downy mildew overwinters on infected crop residue and on the surface of seeds. Although the pathogen can be on seeds, infections throughout the entire seedling are rare. During the growing season, spores are carried to other plants by wind and rain. Extended cool and wet or humid weather conditions make the spread of these spores more extensive.

Symptoms and Scouting

Lesions start as very small green to light yellow spots on the top side of leaves. On the underside of the leaf, fluffy tan tufts of fungal growth occur opposite lesions. Later on in disease development, the yellow lesions become dark brown and brittle. Infected pods do not have visible symptoms but the seed in those pods will be covered with cream to grey masses of oospores.

Management

Soybean varieties that are resistant to downy mildew are available. The disease does not usually become an economic concern.

Phytophthora Root Rot

Phytophthora sojae

Figure 4.178 Phytophthora root rot

Figure 4.179 Split stem with phytophthora infection

Phytophthora root rot can be a devastating disease that affects soybean production worldwide. This disease-causing organism is a water mould or oomycete. Disease development typically occurs in field conditions characterized by heavy, tightly compacted soils, particularly in low-lying and wet areas where the disease often first appears. Infection can occur in patches or be spread throughout the entire field. Phytophthora root rot development is favoured by a wet, warm spring with 25-30 C temperatures. It can attack plants at all stages of growth. Growing susceptible varieties can result in almost total crop loss when conditions are favourable for the disease.

Disease Cycle

The fungus that causes phytophthora root rot forms oospores (thick-walled resting structures) to survive in the soil for many years. In the spring, oospores germinate to produce zoospores when the soil is very wet or flooded or mycelium that can infect roots. Zoospores can move short distances in the soil to root tips, cracks in the outer layer of the plant roots, or seedling hypocotyls. When they reach one of these, they settle and start an infection. After infection and disease development, oospores are produced in the roots and stems. When infected tissue breaks down, the oospores are released into the soil.

Symptoms and Scouting

Symptoms at the pre-emergent and post-emergence stages can cause damping off which can lead to the need to replant. Dying seedling remnants scattered throughout the field may be found. In established plants, it can manifest as a stem or root rot, reducing nutrient flow to the plant causing wilting, foliar chlorosis (yellowing) and eventually plant death. Water-soaked lesions progress up the stem and can be accompanied by yellowing leaves. Scout for phytophthora root rot after prolonged periods of rain when temperatures have been warm.

Figure 4.180 Phytophthora root rot

Management

Resistance has been bred into soybean varieties for this disease, but different resistance genes exist in different varieties. Repeat planting of the same variety with the same resistant gene can, in some cases, lead to the pathogen overcoming resistance. Oospores can survive in the soil for many years, therefore using an extended crop rotation can keep the levels of field infection down. Seed treatments can protect crops in the first few weeks of development but will not protect established plants from infection.

Sclerotinia Stem Rot (White Mould)

Sclerotinia sclerotiorum

Sclerotinia is a fungal disease that affects a wide range of hosts in Saskatchewan. It is common in cool, moist regions but tends to be sporadic, causing severe losses in some fields while resulting in none in adjacent fields. It is more likely to occur in crops with a high yield potential. Plants are killed in patches after the crop canopy closes. Soybean seed containing sclerotia of the fungus are not marketable as food grade. The impact on yield can range from 10 to 20 per cent loss in a moderate infection or can cause a loss of 10 to 20 bushels per acre in severe infections.

Figure 4.181 White mould fungal growth on soybean

Disease Cycle

Refer to Sclerotinia Stem Rot (White Mould) under Common Diseases of Canola and Mustard.

Symptoms and Scouting

Sclerotinia symptoms in soybeans show up as white, bleached lesions on stems, leaves, and petioles. Cotton-white mycelium can be seen on these lesions, which leads to rapid wilting of the plant. As the infection progresses, the affected plants transition from grey to brown. Hard black sclerotia begin to form within the stems and pods. Scout for sclerotinia when the canopy has closed, and humidity is high or the field has received lots of moisture.

Figure 4.182 Stem shredding and sclerotia bodies

Management

Manage sclerotinia in soybeans by including non-host crops in rotation like cereals. If the disease is severe, rotate out of susceptible crops for four or more years. Using a wider row spacing may improve canopy ventilation. Fungicides are available for sclerotinia in soybean but they must be applied before symptoms appear, as the disease only has one generation per year (monocyclic).

Septoria Brown Spot

Septoria glycines

This fungal disease overwinters on infected crop residue. It does not typically cause a major yield impact, but losses of up to 10 per cent have been observed when very susceptible varieties are grown or there are prolonged stress conditions.

Disease Cycle

During the growing season, spores from the infected residue spread the disease via wind and rain. Once infected lesions form on the soybean leaves. Spores are released from the lesions, transferring the infection up the plant onto the leaves, stems, and pods. Spores also infect nearby plants.

Symptoms and Scouting

Dark brown spots less than 3 mm diameter first appear on soybean leaves on the lower part of the plant and then move up as the disease progresses. Irregular brown and yellow patches will be present on the top side of the leaf only. These lesions will coalesce as the disease progresses.

Management

Foliar fungicides are available for this disease. Crop rotation to non-host cereal or oilseed crops is an option if this disease is at high levels in soybean fields.

Figure 4.183 Septoria infection beginning at the bottom of the soybean plant

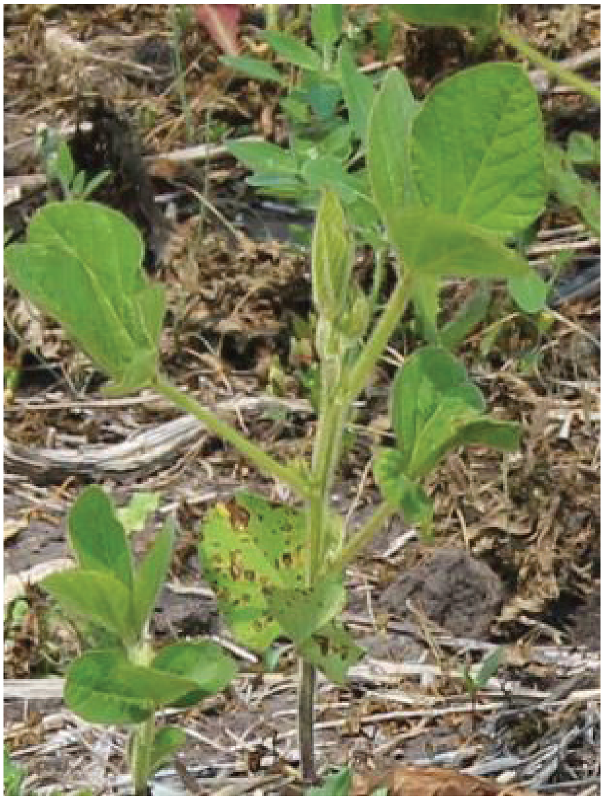


Figure 4.184 Septoria infection in soybean

Sooty Moulds on Field Crops

Alternaria spp., *Cladosporium* spp., *Stemphylium* spp., *Epicoccom* spp.

Sooty mould, or black mold is not a true plant disease but rather a saprophytic fungal growth that develops on dead/dying plant tissue. Sooty mould is normal to see in the late growing season when crop stands have matured and are exposed to moisture. It's common to notice sooty mould on wheat, barley, and canola, especially if there has been recent rain, high humidity, and a delay in harvest. The longer the crop sits out, the more advanced the sooty mould may appear. There is no risk of yield reduction from sooty mould, only a potential negative appearance from darkened discolouration of kernels. Discoloured grain may result in possible downgrading. Grain intended for use as seed should undergo testing for germination, vigor, and pathogen load if it showed advanced sooty mold development when harvested.

Symptoms and Scouting

Sooty mould appears as black speckles on the surface of plant material. In cereals, it can be noticed on the heads, glumes, leaves, and stems. In canola, it may be noticed on pods and stems. When environmental conditions are conducive for fungal growth, sooty mould may appear as a fuzzy dark green or black layer on the outside of seed pods or glumes, sometimes making the whole plant look quite dark in appearance.

Management

No suitable management methods are available for the development of sooty mould. Harvesting crops on time and before fall rain will help reduce the chance of sooty mould developing further.

Figure 4.185 Sooty mould on wheat

Figure 4.186 Sooty mould on rye

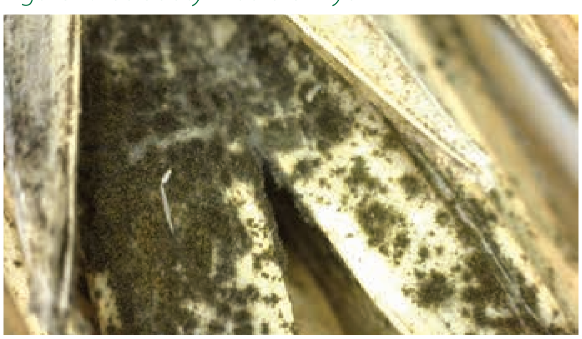
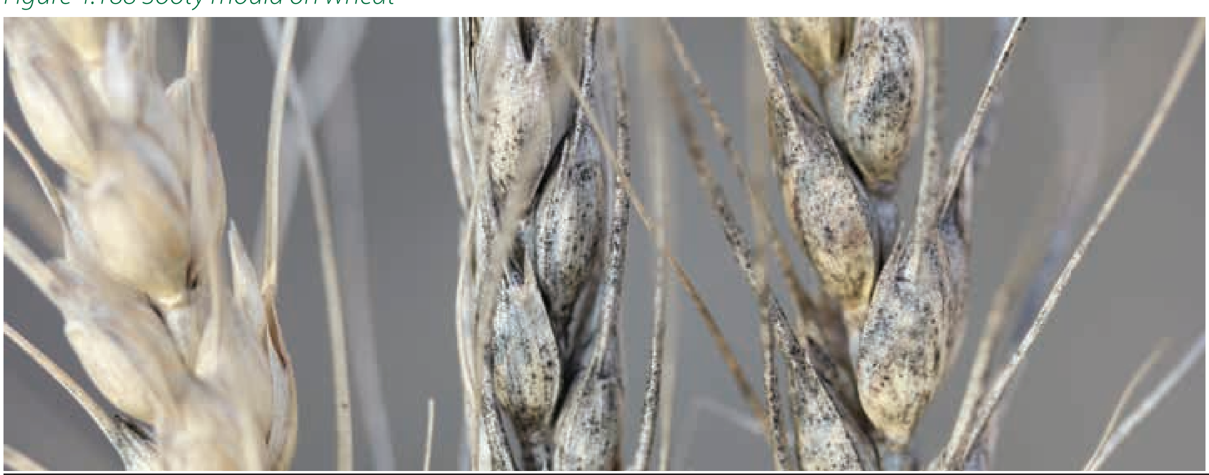


Figure 4.187 Sooty mould on canola pods

Figure 4.188 Sooty mould on wheat



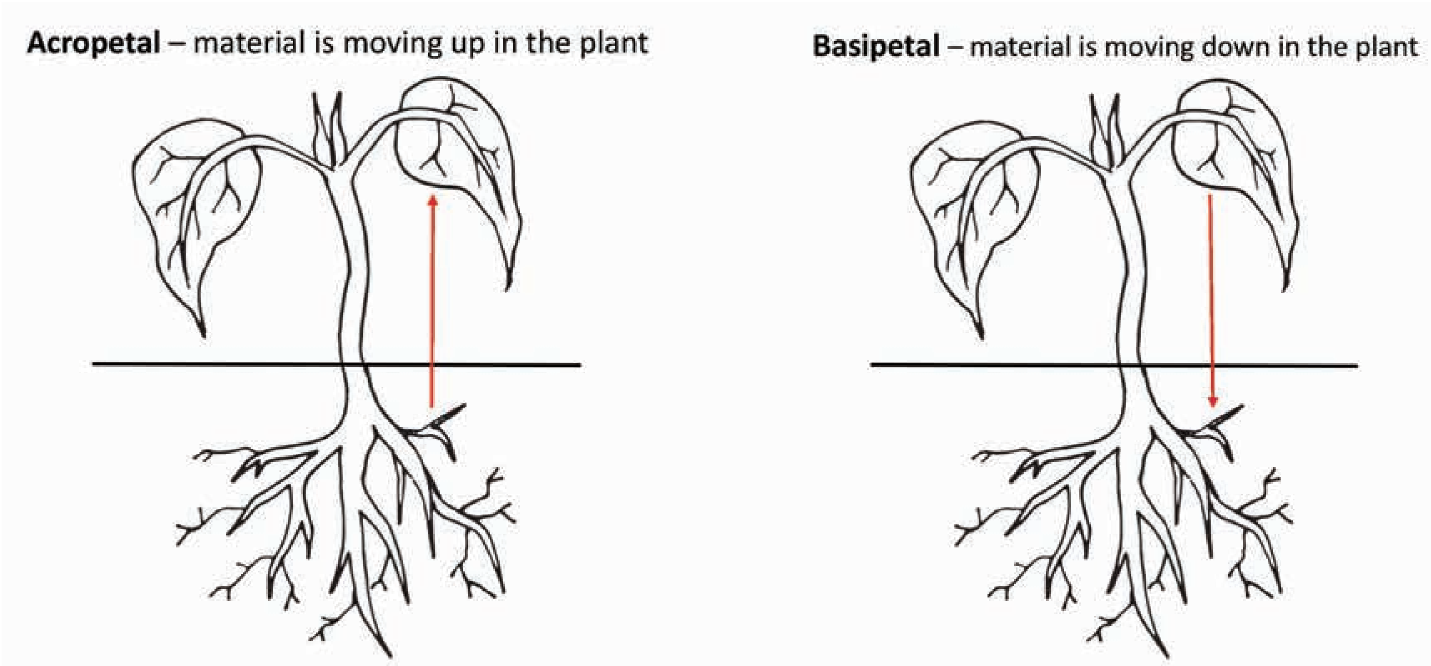
Section 5: Herbicide Groups and Injury

Table 5.1 The Mode of Action, Site of Uptake and Symptoms of Different Herbicide Groups

Herbicide Group	Mode of Action	Site of Uptake	Weed Symptoms/Timing	
			Grass Weeds	Broadleaf Weeds
1	Systemic	Foliar	Reduced growth, yellowing of growing point in one to three weeks. Newest leaf of affected plant pulls out easily in three to five days.	Tolerant
2	Systemic	Foliar/ Soil	Newest leaves yellowed in three to 10 days, death in one to three weeks.	Newest growth discoloured (red/yellow/ purple) and/or miniaturized; the whole plant is involved in one to three weeks.
3	Systemic	Soil	Reduced emergence, poor root development of emerged plants. Roots often swollen/stunted and root tips darkened.	Reduced emergence, poor root development of emerged plants. Roots often swollen/stunted and root tips darkened.
4	Systemic	Foliar	Tolerant to moderate rates. High rates cause symptoms similar to drought. Improper timing may cause kernel abortion in cereal crops.	Abnormal growth (twisted stems, cupped leaves) in two to 10 days.
5	Systemic	Soil	Wilted and yellowed oldest leaves beginning at leaf margins, death in seven to 10 days.	
	Contact	Foliar	Yellowed oldest leaves, death within days.	Yellowed/bleached oldest leaves where spray contacts, death within days.
6	Contact	Foliar	Some leaf tip burn or white tissues possible.	Yellowed leaves in two to four days, death in one to two weeks.
9	Systemic	Foliar	Wilted, yellowed leaves in seven to 10 days. Newest growth is impacted first followed by the rest of the plant.	
10	Contact	Foliar	Wilted, bleached leaves in three to five days, death in one to two weeks.	
13	Systemic	Soil	Bleached leaves, susceptible seedlings die shortly after emergence.	
14	Contact	Foliar	Some leaf burn at contact points or leaf edges.	Leaves yellowed and desiccated in one to three days. (Post-emergence applications)
	Systemic	Soil	Bleaching and yellowing, death prior to or shortly following emergence	
15	Systemic	Soil	Reduced emergence, emerged plants stunted. Leaf rolling (grasses). Leaf tips compressed and crinkled (broadleaves). Buggy-whipping. Plants deep blue-green.	
19	Systemic	Foliar	Twisting of older leaves, new leaves fail to expand, plant death in two to four weeks.	
22	Contact	Foliar	Leaves wilted within hours, desiccated in one to three days.	Leaves wilted in one to three days, desiccated and dead in three to seven days.
26 (grass weeds only)	Systemic	Foliar	Immediate cessation of growth, rapid desiccation of new leaves and purpling and yellowing of older tissues.	See Group 4.
27	Systemic	Foliar	Some bleaching and whitening of leaves.	Leaves bleached and whitened in two to 10 days and death in seven to 10 days.
29	Systemic	Soil	Seedlings fail to emerge.	Seedlings fail to emerge.

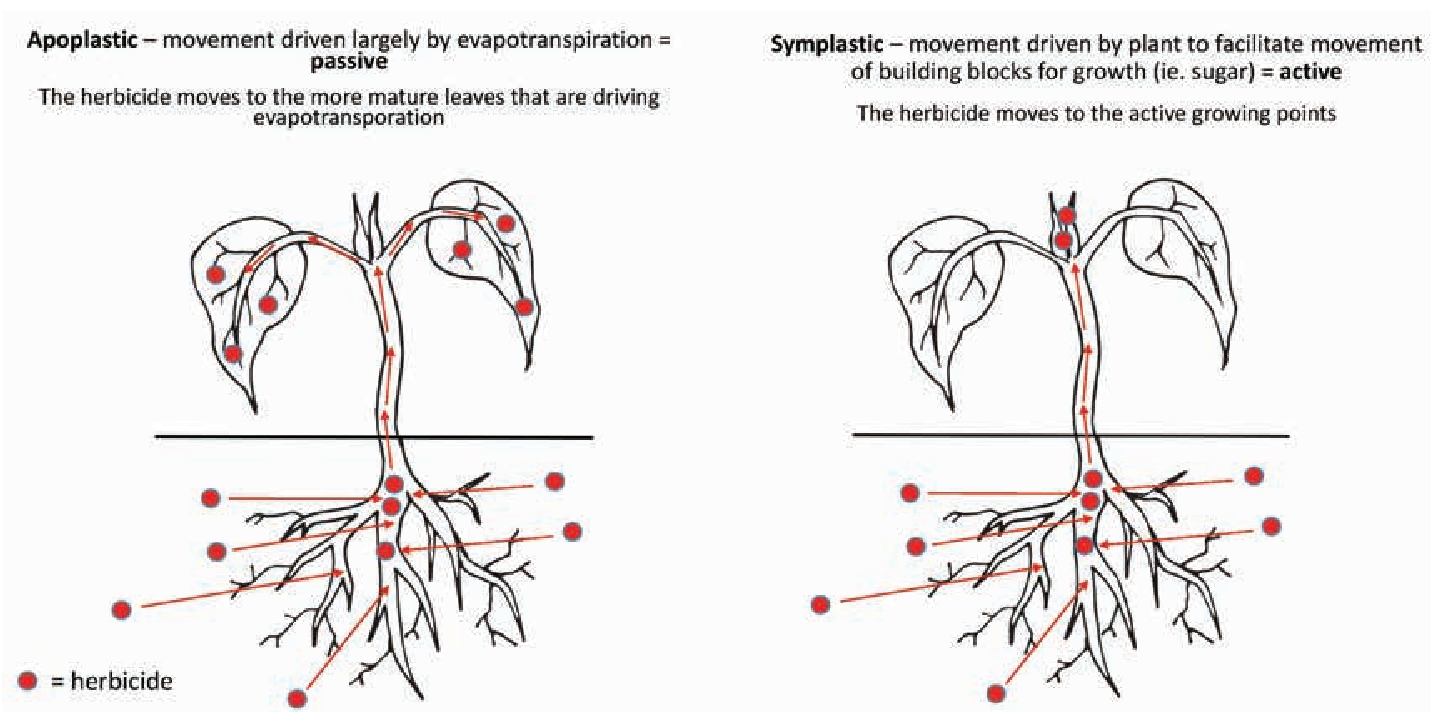
Courtesy of: The Guide to Crop Protection

Movement of Herbicides in the Plant

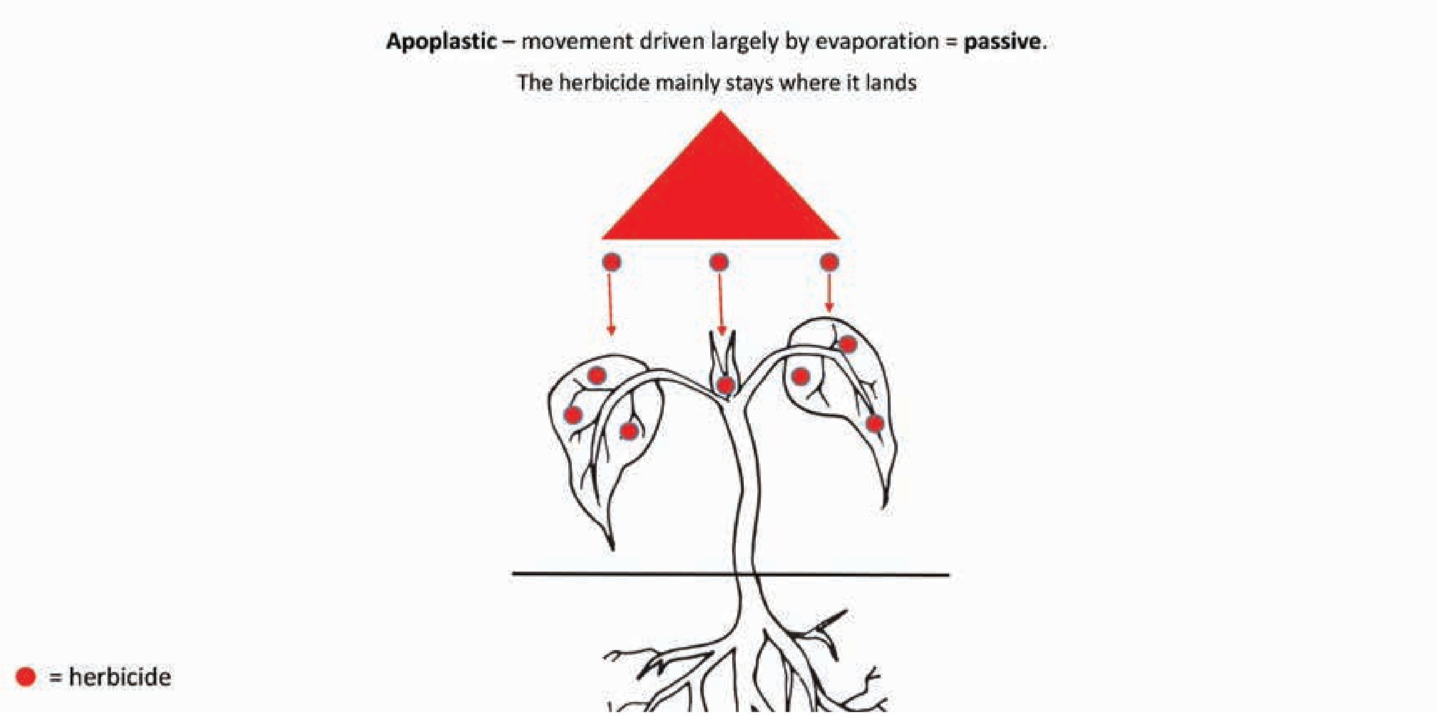


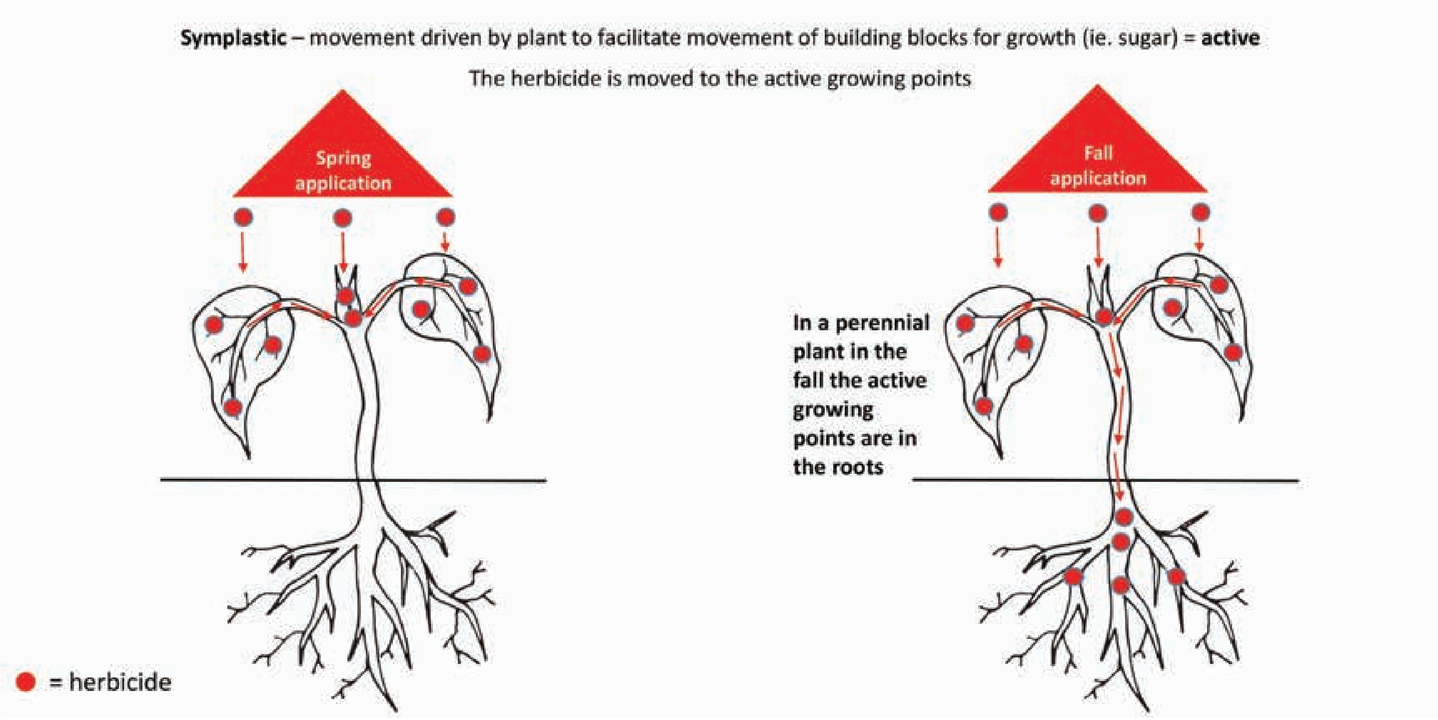
For example-In perennial plants, herbicides that move to the growing points will move up in the spring and move down in the fall.

Movement of Soil Active Herbicides in the Plant



Movement of Foliar Applied Herbicides in the Plant





Herbicide Groups and Injury

Group 1 Herbicides (ACCase Inhibitor)

Figure 5.1 Clethodim applied 10 days earlier

- **Target:** Inhibits the Acetyl Coenzyme A Carboxylase pathway
  - » Blocks the production of fatty acids used in the production of membranes and waxy substances like cuticular wax.
  - » The plant can have trouble defending itself from drying out.
- **Selectivity:** Grasses only.
  - » Products for cereal crops are selective to grassy weed species.
  - » Products for broadleaf crops are non-selective to grassy plants.
  - » May have adjuvant/solvent related effects on broadleaf plants.
- **Plant Uptake:** Largely foliar.
- **Movement in Plant:** Symplastic/active to areas of new growth.
- **Soil activity:** Little to none.
- **Binding to Soil:** Low to strong (product dependent).
- **Breakdown:** Rapidly in soil by:
  - » UV radiation (also on leaf surface-"dims").
  - » Microbial degradation.
  - » Hydrolysis (a water molecule cleaves the active ingredient molecule in half and deactivates it as a herbicide) in some cases.
- **Symptoms:** Whitening and interveinal chlorosis at the growing point and new growth followed by growth of the growing point stopping progression.

Group 1 Injury Symptoms on Tolerant Crops:

- Symptoms often associated with cold or saturated soils.
- The plant is temporarily unable to break down herbicide normally.
- Bands occur proportional on each leaf to where it was at the time of the cold weather event.
  - » i.e. lower on older leaves and higher on newer leaves.
- Reduced growth and yellowing of the growing point within one to three weeks. Within three to five days, the newest leaf of affected plants can be pulled out easily.
- If there is green growth below the band, the plant will recover and there usually is no yield loss.

Figure 5.2 Group 1 injury symptoms to tolerant crop-white or yellow banding

Figure 5.3 Pull test on susceptible species

Courtesy of: University of Saskatchewan

The "pull test" for Group 1 activity on susceptible species:

- Tug on youngest leaf. If it pulls out easily and the base is discoloured, the herbicide is working (as early as five to seven days after treatment (DAT)).

Figure 5.4 Lethal dose of quizalofop on wild oats 9 DAT

Courtesy of: University of Saskatchewan

Figure 5.5 Base of a wild oat, 26 days after application with sublethal dose of quizalofop

Courtesy of: University of Saskatchewan

Group 2 Herbicides (ALS/AHAS Inhibitors)

- **Target:** Inhibits Acetolactate Synthase (ALS) also called Acetohydroxy Acid Synthase (AHAS).
  - » Blocks production of the essential branched chain amino acids leucine, isoleucine and valine. This prevents the plant from creating essential proteins necessary for development of new tissues and repair of old tissues.
- **Selectivity:** both grass and broadleaf crops.
  - » Controls a range of grasses and/or broadleaves (active specific).
- **Plant Uptake:** Both foliar and root uptake.
- **Movement in Plant:** Symplastic/active to areas of new growth.
- **Soil Activity:** Significant.
- **Binding to Soil:** Little. Persistent products can be very mobile in the soil.
- **Breakdown:**
  - » Little to significant soil persistence (from very quick breakdown to years).
  - » Both hydrolysis and aerobic microbial breakdown-product dependent.
  - » Imidazolinone products are bound more by acid soils and will breakdown slower.
  - » Sulfonylurea products are bound more by high pH soils and breakdown will be slower, especially with hydrolysis.
  - » Triazolopyrimidines and sulfonylaminocarbonyl-trazolinone products have some binding to organic matter that can buffer some soil activity.
- **Symptoms:**
  - » Symptoms in grass weeds include yellowing of the newest leaves within three to 10 days followed by plant death in one to three weeks.
  - » Symptoms in broadleaf weeds include a discoloured (red/yellow/purple) growing point and new growth of plant. Yellow discolouration spreads to the whole plant within one to three weeks.
  - » When there is soil residue, seedlings will emerge but once they run out of these amino acids from the seed they may start to show symptoms.

Figure 5.6 Thifen:Triben (2:1) lethal rate on beans 4 DAT

Courtesy of: University of Saskatchewan

Figure 5.7 Thifen:Triben (2:1) lethal rate on beans 12 DAT

Courtesy of: University of Saskatchewan

Figure 5.8 Imazamox/Imazethapyr on canola 7 DAT

Group 2 Injury Symptoms on Tolerant Crops:

- Symptoms often associated with:
  - » Cold or saturated soils.
  - » Soil residue carryover from dry conditions the previous season followed by moderate to heavy rain.
- Stunting, shortened blade to sheath ratio, shortening of internode regions of the stem for broadleaf crops. The space between nodes for broadleaf crops will be affected for growth after the herbicide application but not before.
- Loss of apical dominance with prolific branching.
- Inter-veinal yellowing beginning in the newest growth.
- Depending on severity and persistence of exposure, the plant may or may not recover.

Group 3 Herbicides (Microtubule Inhibition)

- **Target:** Bind to tubulin preventing polymerization into microtubules
  - » Microtubules are a critical part of cell division and cell wall formation.
- **Selectivity:** Impacts both grasses and broadleaves.
- **Plant Uptake:** Absorbed through the roots.
- **Movement in Plant:** No appreciable movement past roots.
- **Soil Activity:** Significant for soil applied herbicides.
- **Binding to Soil:** Bound tightly (ethalfluralin) to very tightly (trifluralin) to clay and organic matter.
- **Breakdown:**
  - » Anaerobic microbial degradation is rapid.
  - » Aerobic breakdown is moderate to slow.
- **Half-life:** ethalfluralin 24 to 47 days; trifluralin-average 164 to 544 days (dependent on environmental field conditions and strength of binding to soil).
  - » Volatilization (soil incorporation will prevent this).
  - » UV degradation (soil incorporation will prevent this).

Group 3 Injury Symptoms:

- The primary symptoms are in the roots:
  - » Stubby and clubbed roots that fail to elongate.
  - » Symptoms in the upper part of the plant are a result of the deficiencies caused by damage to the roots.
- There can be stunting in young shoots.
- Symptoms in grassy weeds include reduced emergence and poor root development of emerged plants. Roots are often swollen or stunted and root tips are darkened.
- In broadleaf weeds, symptoms include reduced emergence and poor root development in plants that have emerged.
- Symptoms in the upper part of the plant are a result of the deficiencies caused by damage to the roots.

Figure 5.9 Ethalfluralin (1100g active ingredient (ai)/ha) on barley

Courtesy of: University of Saskatchewan

Figure 5.10 Ethalfluralin (1100g ai/ha) for fall pre-plant incorporates on wheat (untreated on left)

Courtesy of: University of Saskatchewan

Group 4 Herbicides (Synthetic Auxin)

- **Target:** Several targets within the plant. Products mimic the function of Indole Acetic Acid (IAA) but susceptible plants are unable to metabolize it.
  - » Results in unregulated cell elongation and production of undifferentiated (callus) tissues particularly at the root/stem interface.
- Sub-lethal symptoms include epinasty, cupping and a leathery appearance.
- Initial symptoms show up within hours. Plant death does not occur for three to four weeks.
- **Selectivity:** Broadleaves are the most sensitive; grassy plants tolerate product in the group but they are not resistant.
- **Plant Uptake:** Through both roots and shoots.
- **Movement in the Plant:** Symplastic/active to the same sites as natural plant hormones.
- **Soil Activity:** Little to significant, depending on product persistence.
- **Binding to Soil:** Low.
- **Breakdown:**
  - » By aerobic soil microbes.
  - » Products range from short to very long persistence in soil.

Group 4 Injury Symptoms:

- Broadleaves are the most susceptible. Symptoms include:
  - » Epinasty twisting of stems and petioles.
  - » Stem swelling particularly at the lower stem/upper root.
  - » Stem elongation promotes cell expansion in stems as with natural auxin.
  - » Cracks and splits in bark growth of undifferentiated cells (callus tissue).
  - » Leaf "warting" resembling infection by a virus.
  - » Brittleness of affected plants (stems, petioles, mid-ribs of leaves).
  - » Chlorosis in the growing point.
  - » Cupped and curled leaves.
  - » Wilting and tissue death (necrosis) as a result of crushing of xylem transport vessels.
- Initial symptoms are visible within hours. Plant death occurs in three to four weeeks.
- Sub-lethal symptoms include epinasty, cupping and leathery appearance.
- Grasses are tolerant but not immune and symptoms are typically associated with improper timing or excessive rates. Symptoms include:
  - » Physiology of the water transport vessels resist crushing (under moderate rates).
  - » Metabolism is faster than for broadleaf crops.
  - » Plants can appear drought stressed even when there is enough moisture.
  - » Applications too early during head formation or too late can lead to floret abortion and head kinking, which reduces yield and causes flag leaf "pig-tailing".
  - » Too high of rates can result in symptoms similar to drought, including older leaves dying, blue-grey leaf surfaces form thicker/waxy cuticles, stunting and shorter flag leaf.

Figures 5.11 2,4-D on dandelion

Courtesy of: University of Saskatchewan

Figure 5.12 2,4-D (420g ai/ha) on sunflower 4 DAT

Courtesy of: the University of Saskatchewan

Figure 5.13 Clopyralid soil residue on soybean

Figure 5.14 Group 4 injury on canola

Figure 5.15 Clopyralid soil residue on peas

Figures 5.16 Phenoxy damage on cereals' head

Courtesy of: the University of Saskatchewan

Figure 5.17 Phenoxy damage on cereals' head that can result in "pigtail" appearance

Figure 5.18 2,4-D drift on canola

Figures 5.19 Phenoxy damage on cereal heads

Courtesy of: the University of Saskatchewan

Figure 5.20 Dicamba damage on common bean

Courtesy of: University of Saskatchewan

Figure 5.21 Clopyralid gradient showing effects on peas

Courtesy of: University of Saskatchewan

Figure 5.22 2,4-D corn root damage

Figure 5.23 2,4-D corn root damage

Note: This damage only occurs if 2,4-D is sprayed after the sixth leaf stage

Group 5, 6 and 7 Herbicides (Photosystem II Inhibitors)

- **Target:** Inhibit photosynthesis by blocking electron transport.
  - » Rapidly ruptures cell membranes.
  - » Rapid chlorosis transitioning quickly to necrosis of leaf tissue (two days in warm, sunny weather).
- **Selectivity**:
  - » Group 5 and 7 both control grasses and broadleaves. Grasses at higher rates typically.
  - » Group 6 primarily controls broadleaves but grasses may be injured.
  - » Application at high temperatures can result in injury to crops that should be tolerant. The herbicide acts faster than the plant can metabolize it.
- **Plant Uptake:** The majority of plant uptake is aboveground. Root uptake occurs for Group 5 and 7 products.
- **Movement in the Plant:** Acropetal/passive.
  - » Move upward and outward in plants.
  - » Concentrates herbicide in leaf margins or tips at sub-lethal rates.
- **Soil Activity:** Significant soil activity for Group 5 and 7; no soil activity for Group 6.
- **Binding to Soil:**
  - » Group 5 and 7 low to moderate binding; available for root uptake.
  - » Group 6 bound tightly to soil and not available for root uptake.
- **Breakdown:** Primarily aerobic microbial; some Group 5 also via hydrolysis.

Group 5 Injury Symptoms:

- Symptoms on weeds from soil application include wilting and yellowing of the oldest leaves. Plants die in seven to 10 days.
- On grassy weeds that have received a foliar application, symptoms include yellowing of the oldest leaves and plant death within days.
- On broadleaf weeds that receive a foliar application, the oldest leaves become bleached and death occurs within days.

Group 6 Injury Symptoms:

- When applied to grassy weeds, some leaf burn is possible.
- When applied to broadleaf weeds, leaves are yellowed in two to four days, and plants die in one to two weeks.

Group 7 Injury Symptoms:

- Symptoms when soil applied include yellowing and stunted plants followed by plant death in 10 to 14 days.
- Symptoms when foliar applied include inter-veinal yellowing on the oldest leaves and plant death within days.

Figure 5.24 Bromoxynil sublethal rate on sunflower 4 DAT

Courtesy of: University of Saskatchewan

Figure 5.25 Bromoxynil lethal rate on wild mustard 4 DAT

Courtesy of: University of Saskatchewan

Figure 5.26 Metribuzin uptake by roots after heavy rain

Figure 5.27 Group 6 Bentazon drift on lentils

Group 9 Herbicides (EPSP Amino Acid Synthase Inhibitor)

- **Target:** Inhibits 5-enolpyruvyl shikimate-3-phosphate synthase.
  - Results in depletion of tryptophan, tyrosine, and phenylalanine.
  - Group 2 and Group 9 symptomology appear similar and can be difficult to tell apart. The main difference is:
    - Glyphosate remains active in the plant for 24 to 48 hours before being bound up within it. Plant growth ceases before symptoms develop.
    - Group 2 herbicide symptoms can appear and progress repeatedly in affected plants. Plants do not recover because Group 2 products can persist in the plant and soil. Group 9 products do not persist in the soil.
- **Selectivity:** Non-selective, except genetically engineered plants bred to tolerate glyphosate.
- **Plant Uptake:** Foliage only. Very high mobility in the xylem and phloem.
- **Movement in the Plant:** Symplastic/active-moves to most actively growing points in the plant.
  - In the spring, movement is to top growth
  - In the fall in perennial plants, movement is to the roots.
- **Soil Activity:** None in most soils. There may be some effects with high rates applied in low cation exchange category soils (low organic matter sand).
- **Binding to Soil:** Glyphosate becomes unavailable to the plant when bound to organic matter and clay.
- **Breakdown in Soil:** Aerobic microbes.
  - Moderate persistence in soil but the herbicide is tightly bound so it doesn't impact crops.

Group 9 Injury Symptoms:

- Immature leaves at the growing point are affected first (five to seven days) and older leaves follow (up to three weeks).
- Symptoms include wilted and yellowed leaves in seven to 10 days. The newest growth is impacted first, followed by the rest of the plant.
- Sub-lethal effects include:
  - Yellowing of the new growth (first to experience the deficit of essential amino acids for growth).
  - Stunting and mineralization of new growth.
  - Loss of apical dominance and the eruption of lateral buds.
  - Compression of the newest internodes.

Injury Diagnostic Tip:

Before deciding that there has been glyphosate injury, make sure it isn't just the crop that is affected. Check leaves of weeds and other plants. Colour change can be due to a number of reasons.

Figure 5.28 Glyphosate symptoms on canola

Courtesy of: University of Saskatchewan

Figure 5.29 Glyphosate (0.5L/ac) on barley 4 DAT

Courtesy of: University of Saskatchewan

Figure 5.30 Sublethal glyphosate injury on flax

Figure 5.31 Damage to pea by glyphosate

Group 10 Herbicide (Glutamine Synthase Inhibitors)

- **Target:** Glutamine synthase inhibition.
  - » Binds irreversibly to the active site of glutamine synthase causing a buildup of ammonia in the cell causing cell rupture and plant tissue death.
  - » Depletion of amino acids (glutamine, glutamate and others).
  - » Growth inhibition & chlorosis or bleaching.
- **Selectivity:** Non-selective, except genetically modified plants bred to tolerate.
- **Plant Uptake:** Foliar.
- **Movement in the Plant:** Rapid contact action traps herbicide and limits translocation within the plant.
- **Soil Activity:** Limited.
- **Binding to Soil:** Weak.
- **Breakdown in Soil:** Rapid aerobic microbial breakdown.
  - » Glufosinate is the only active relevant to Western Canada in this group.

Group 10 Injury Symptoms:

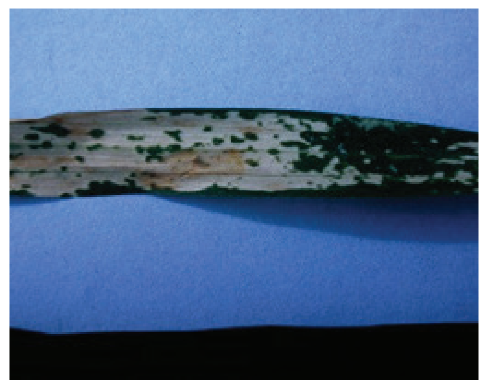
- Symptoms are varying degrees and speeds of:
  - » If dry down of plant tissue is very fast, the movement of glufosinate into the plant will be minimized. This results in a bleaching affect.
- Desiccated tissue from glufosinate looks whiter than desiccated tissue that is a result of the application of other membrane-disrupting herbicides.

Figure 5.32 Glufosinate on canola 4 DAT

Figure 5.33 Glufosinate on sunflower 7 DAT

Courtesy of: University of Saskatchewan

Figure 5.34 Glufosinate on oat 5 DAT



Courtesy of: University of Saskatchewan

Figure 5.35 Glufosinate drift on Roundup Ready canola

Group 13 Herbicides (DOXP Inhibitors)

- **Target:** Inhibitors of 1-deoxy-d-xylulose 5-phosphate synthase.
  - » Inhibits pigment production (including carotene and chlorophyll).
  - » Results in colourless (white) tissue production.
  - » Also may inhibit gibberellin synthesis.
  - » Causes internode stunting or dwarfism.
- **Selectivity:** Corn and soy have high tolerance; canola is tolerant at lower rates.
- **Plant Uptake:** Root.
- **Movement in Plant:** Acropetal/passive translocation.
- **Soil Activity:** Significant.
- **Binding to Soil:** Moderate.
- **Breakdown:** Broken down by microbes.
  - » Short to moderate persistence.
  - » Clomazone is the only active in this group.

Group 13 Injury Symptoms:

- Susceptible plants typically emerge from the soil white, often becoming translucent at the leaf tips, and turn necrotic and die in short order.
- Plants exposed after emergence exhibit bleaching symptoms.

Figure 5.36 Canola showing damage from Clomazone

Figure 5.37 Wheat showing damage from Clomazone

Group 14 Herbicides (PPO Inhibitors)

- **Target:** Inhibitors of protoporphyrinogen oxidase (PPO).
  - » Inhibit heme and chlorophyll biosynthesis.
  - » Inhibits Protox enzyme causing ruptured cell membranes.
- **Selectivity:** Some chemistries selective; others are not.
- **Plant Uptake**: Foliar and root (product dependent).
- **Movement in Plant:** Acropetal/passive movement for products with soil activity.
  - » Rapid necrosis from foliar products limits phloem movement.
- **Soil Activity:** Little to significant (product dependent).
- **Binding to Soil:** Light.
- **Breakdown in Soil:** Aerobic microbes.
  - » Very short to long persistence.

Figure 5.38 Sulfentrazone symptoms on barley

Group 14 Injury Symptoms:

- Symptoms when products are soil applied are bleaching and yellowing and seedling death prior to or shortly after emergence. If the herbicide moves up with water into the plant during the day, there can be veinal chlorosis and symptoms spread from the veins out.
- Symptoms for foliar application to grassy weeds include leaf burn at contact points or leaf edges, rapid desiccation and necrosis.
- For broadleaf weeds, symptoms include yellow leaves and desiccation in one to three days when application is after seedling emergence.
- Regular banding or bleaching and pinching along leaves similar to heat banding that only occur under very saturated soils and sunny conditions that liberate the sulfentrazone from soil near the plant. If this happens during the day, the banding or bleaching and pinching occurs. If the product moves into the leaves at night, the plant has enough time to break down the herbicide and there is no impact on leaf tissue.
- Sub-lethal doses can result in herbicide symptoms being concentrated at the leaf margins.

Figure 5.39 Sulfentrazone symptoms on sunflower

Figure 5.40 Sulfentrazone symptoms on pea

Courtesy of: University of Saskatchewan

Group 15 Herbicides (Long-chain Fatty Acid Inhibitor)

- **Target:** Very long-chain fatty acid (cell membrane, cuticle formation).
  - » Root and shoot growth inhibitors that prevents elongation of roots and shoots.
  - » Susceptible plants fail to form a cuticle layer and typically do not emerge.
- **Selectivity:** All products will control grass and broadleaf weeds except Triallate that is designed for wild oat control only. Small-seeded weeds are more susceptible. The larger the seed size, the less activity there is on that plant.
- **Plant Uptake:** Emerging shoot through treated soil layer. Some via roots.
- **Movement in Plant:** Acropetally/passive but not very far from the point of uptake. In larger plants, there is acropetal movement but there is no impact on the plant.
- **Soil Activity:** Significant; moderately persistent.
- **Binding to Soil:** Light to strong in dry soil.
- **Breakdown in Soil:** Primarily by aerobic microbes. Volitalization can occur when exposed to water and requires soil incorporation to prevent this
  - » Short to moderate soil persistence.

Figure 5.41 leaf tip caught in sheath of prior leaf and leaf rolling

Group 15 Injury Symptoms:

- Symptoms are reduced emergence and stunted plants. Leaf rolling can occur in grasses and compressed and crinkled leaf tips in broadleaves. Buggy whipping may be evident and plants can turn a deep blue-green.
- Seedlings are largely impacted where the product is absorbed by the emerging shoot.

Figure 5.42 Triallate symptoms on oat (injured plants are on the right)

Courtesy of: University of Saskatchewan

Group 19 Herbicides (Auxin Transport Inhibitors)

- **Target:** Concentrates both natural and synthetic auxins (Group 4) in meristematic tissues.
  - » Interferes with plant hormone movement from the top of the plant to the rest of the plant.
  - » Acts as a synergist to non-phenoxy Group 4 herbicides (i.e. dicamba, picloram, aminopyralid, etc.) resulting in efficacy at lower use rates.
- **Selectivity:** Primarily broadleaf (diflufenzopyr); annual grass and broadleaf weeds (naptalam).
- **Plant Uptake:** Foliar and root.
- **Movement in Plants:** Both apoplast/passive and symplast/active.
- **Soil Activity:** Little to significant depending on the product.
- **Binding to Soil:** Light.
- **Breakdown in Soil:** By microbes in soil.
  - » Non-persistent in soil (diflufenzopyr) to slightly persistent (naptalam).

Figure 5.43 Group 19 injury to dicamba-tolerant soybeans from an application of diflufenzopyr

Figure 5.44 Soybean damage caused by diflufenzopyr

Group 19 Injury Symptoms:

- Injury symptoms include twisting of older leaves and new leaves that fail to expand. Plant death occurs in two to four weeks.

Distinct symptoms on dicamba-tolerant soybeans:

Note: symptoms of reduced leaf growth and clustering of growth around nodes. Blank internodes. There may also be other epinasty (cupping, curving, puckering) symptoms.

Group 22 Herbicides (Photosystem I Inhibitor)

- **Target:** Inhibits electron transport.
  - » Rapid membrane disruption causes rapid desiccation.
- **Selectivity:** Non-selective, contact herbicides.
- **Plant Uptake:** Foliar. Good coverage is needed so the product goes into the leaf axils where new leaves are forming.
- **Movement in Plants:** Apoplastic/passive; movement limited due to soil binding.
  - » Possible diffusion in darkness.
- **Soil Activity:** None.
- **Binding to Soils:** Extremely strongly bound to soils-nearly irreversible.
- **Breakdown:** Soil-microbial; on plant tissues by sunlight.
  - » Very persistent (but not active since the product is so strongly bound).

Group 22 Injury Symptoms:

- Injury symptoms in grassy weeds include wilted leaves within hours of application and plant death occurs in one to three days.
- Symptoms in broadleaf weeds include wilted leaves within one to three days after application and the plant desiccates and dies within three to seven days.

Figure 5.45 Initial symptoms of diquat activity

Courtesy of: University of Saskatchewan

Figure 5.46 Figure 5.55 Diquat lethal rate on Desi chickpea 2 DAT

Courtesy of: University of Saskatchewan

Figure 5.47 Paraquat on wheat 1 DAT

Courtesy of: University of Saskatchewan

Figure 5.48 Paraquat on wheat seedlings 2 DAT

Group 26 Herbicides (Unknown)

Figure 5.49 Group 26 on green foxtail

Courtesy of: University of Saskatchewan

- **Target:** Suggested cell wall biosynthesis inhibitor.
  - » Quinclorac is the only active in this category. It displays two modes of action. Quinclorac has activity on grasses (Group 26 portion) as well as broadleaves (Group 4 portion).
  - » Research also suggests the stimulation of 1-aminocyclopropane-1-carboxylic acid resulting in overproduction of ethylene and cyanide.
  - » This is seen in some other auxinic herbicides as well.
  - » Causes sub-lethal sterility in oats (domestic and wild).
- **Selectivity:** Quinclorac has activity on grasses.
- **Plant Uptake:** Absorbed by roots and shoots.
- **Movement in Plants:** Both apoplast/passive and symplast/active.
- **Soil Activity:** Significant; moderately persistent (may injure the year after treatment).
- **Binding to Soil:** Limited binding resulting in potentially fairly mobile herbicides.
- **Breakdown:** Primarily degraded by microbes in soil.

Group 26 Injury Symptoms:

- The systemic herbicide is absorbed by germinating seeds, roots and leaves of seedlings.
- Symptoms in sensitive monocots start to appear seven to 10 days after application. Plant growth is then inhibited followed by the chlorosis of young leaves. Necrosis of the aerial parts of the plant occurs next.
- Purpling can be caused by the cyanide in the plant.

Group 27 Herbicides (HPPD Inhibitors)

- **Target:** Inhibit 4-hydroxyhenyl-pyruvatedioxygenase
  - » Indirect inhibition of carotenoid (pigment) production.
  - » Carotenoid pigments protect chlorophyll from decomposition by sunlight.
  - » Without carotenoid pigments, chlorophyll is photo-oxidized and chloroplasts break down.
- **Selectivity:** Targets grassy and broadleaf weeds in both grass and broadleaf crops.
- **Plant Uptake:** Both foliar and root.
- **Movement in Plants:** Acropetal/passive-sublethal accumulation at leaf edges.
- **Soil Activity:** Low to significant.
- **Binding to soil:** Little.
- **Breakdown:** Aerobic microbes in soil.

Group 27 Injury Symptoms:

- Symptoms on grassy weeds include some bleaching and whitening of leaves.
- Symptoms in broadleaf weeds include bleaching and whitening of leaves within two to 10 days and the plant dies in seven to 10 days.
- Symplastic movement only, which means upward and outward movement and results in halo effects on leaves.
- Older leaves are impacted.

Figure 5.50 Pyrasulfatole and bromoxynil on canola

Figure 5.51 Pyrasulfatole and bromoxynil on lentil

Note: Lentil in Figure 5.51 is also suffering from Group 2 injury caused by Pursuit (imazethapyr) applied prior to seeding.

Figure 5.52 Pyrasulfatole soil residue on lentil

Figure 5.53 Pyrasulfatole soil residue on pea

Group 29 Herbicide: Cellulose biosynthesis inhibitor

The only Group 29 herbicide we have registered is Esplanade SC, which is used for non-crop areas where bare ground is desired (i.e., rights-of-way, roadsides, industrial sites, fence lines). DO NOT apply to cropland.

- **Target:** Inhibits cellulose biosynthesis
- **Selectivity:** Non-selective.
- **Plant Uptake:** Soil
- **Movement in Plant:** Systemic mode of action
- **Soil activity:** Very persistent in soil and relies on rainfall to move it into the soil. Leaching can occur.
- **Binding to soil:** Strong
- **Breakdown:** Breaks down mainly through biotic degradation and leaching. Has a long residual with a half life >150 days.

Symptoms:

- Applied pre-emergence - seedlings fail to emerge.
- Applied postemergence – symptoms include stunted growth and root swelling or clubbing of the roots.

Adjuvants: Activators vs Utility Modifiers

Adjuvants are a common addition to sprayer tanks during the season. An adjuvant is added to a pesticide product or pesticide spray mixture to enhance the pesticide's performance and/or the physical properties of the spray mixture. Always read and follow pesticide label directions as some pesticides do not require additional adjuvants and may cause damage to crops or reduce efficacy. There are two main classes of adjuvants: "activators" or "spray modifiers" (including surfactants and crop oils), and "utility modifiers" (including pH adjusters, water conditioners, low-drift adjuvants, and anti-foaming agents).

Activators

Activator adjuvants are designed to improve pesticide activity. This is done through several different products that can be blended into the pesticide. They are surfactants and oils.

Surfactants change the physical properties of a spray solution as well as the droplet size. They help improve many properties of pesticides. The two main types of surfactants are anionic and non-ionic. Anionic surfactants carry a negative charge. Non-ionic surfactants do not carry a charge.

The properties of surfactants improve the emulsification and dispersion of herbicides. They also help with spreading and sticking active ingredients to the leaf surface. This is done by reducing the surface tension of the spray mixture, forming a bridge between the water and the waxy leaf surface, allowing better adhesion. This increases the likelihood that the spray droplet will stay on the leaf surface without rolling off. Surfactants can also help increase the fluidity of waxy cuticles to assist with the uptake of the active ingredient into the plant. An example of how the activators work on the leaf is on the next page.

Many factors can affect the effectiveness of surfactants. Environmental factors, physiological features of the plant such as the texture of the leaf, as well as interactions between the surfactant, pesticide, and the carrier can change how effective the surfactant is.

If labels are not correctly followed, harmful damage can occur to the crop from adjuvants. Some activators that work well with one herbicide, can reduce the activity of another or may not work at all. An example of this is crop oil concentrates or COCs are less effective than the adjuvants built into glyphosate.

Please refer to the Saskatchewan Guide to Crop Protection for a list of adjuvants that are used within Western Canada.

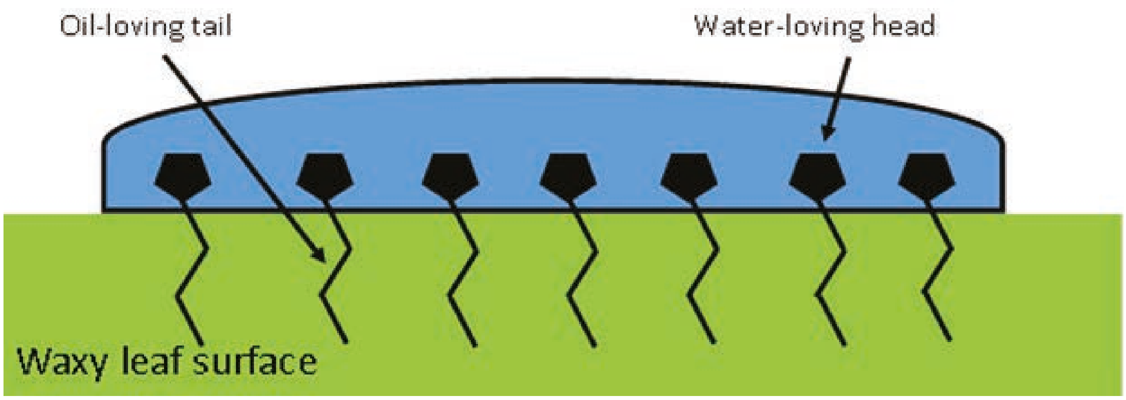
Utility Modifiers

Utility modifiers usually do not enhance the efficacy of the herbicides but enable the active ingredient to perform as expected. Among the group of utility modifiers, there are: defoamers, pH adjusters, water conditioners and drift control agents. These are added when conditions require them. For example, when water hardness is high, when foaming becomes excessive or when drift is problematic.

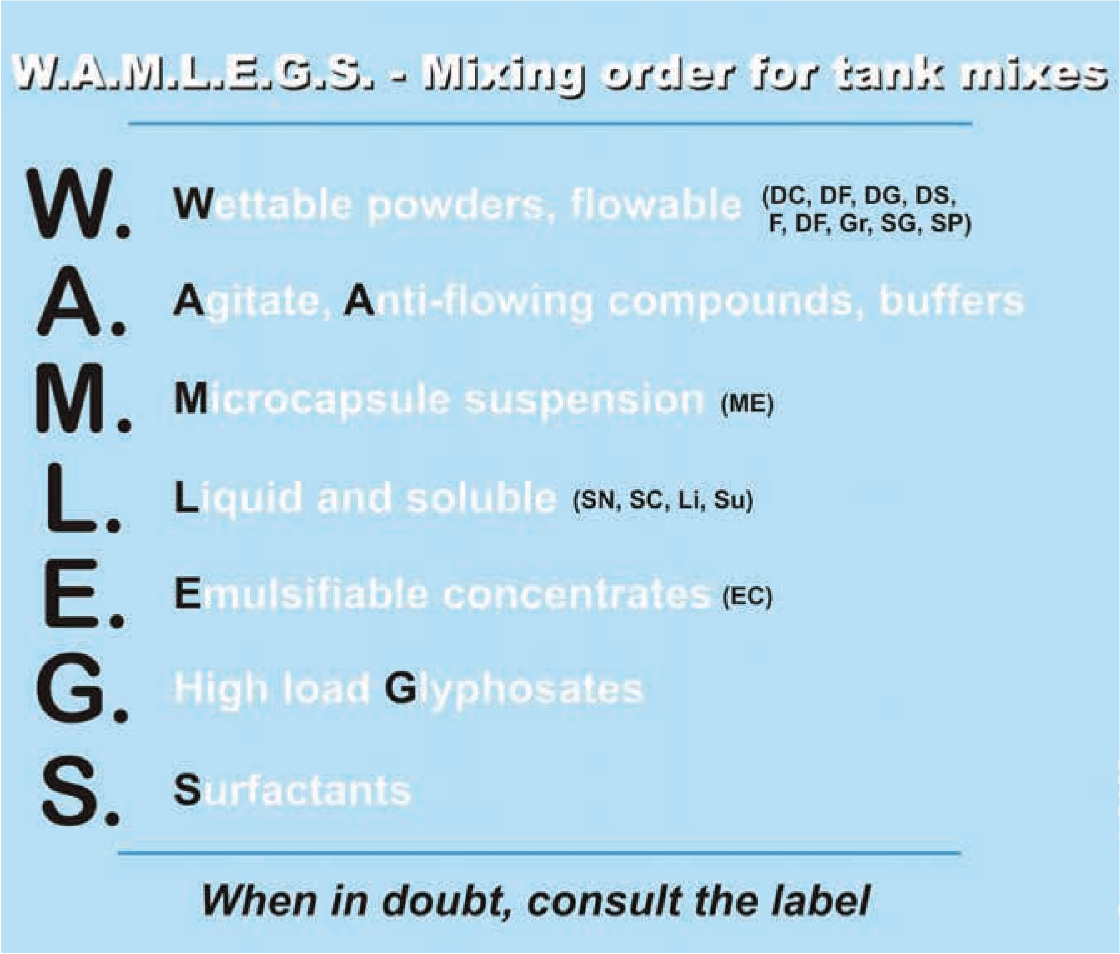
Pesticides can be sensitive to pH. Some require a low pH to dissolve and others require a high pH. It is important to note the requirements of the tank mix before adjusting the pH. Group 2 imidazolinones prefer a lower pH and sulfonylureas prefer a higher pH. Ingredients not properly dissolved within the solution may cause poor weed control and increase the risk of chemical hang-up in the sprayer.

Drift control agents are also utility modifiers. They improve spray patterns to help prevent drift. Their key feature is to reduce driftable, fine droplets by roughly 50 per cent. It is important to use the proper nozzle type required for the pesticide and adjuvant combination. Check the label of the drift control agent before using on a pesticide.

Figure 5.54 How a surfactant/activator functions on a waxy leaf cuticle.



Mixing Order for Tank Mixes



Courtesy of BASF

If tank mixing is not done in the correct order, the result could be a tank-load of material that may not control the target pests, cause injury to the crop, plug nozzles, or leave an undesirable residue in the tank that will require extensive cleaning. Mistakes like these are costly, could put the user at unnecessary risk of exposure to the products, or create an environmental disposal problem. To avoid mixing that may result in incompatibilities, always consult the label of the products that are being used to learn the correct order. Remember to add all like components at the same stage of mixing. Learn more in the latest Guide to Crop Protection.

Sprayer Tank Cleaning

- When pesticide application is completed each day, it is important to empty and clean the sprayer thoroughly to prevent the breakdown of certain pesticides, prevent adhesion of the pesticide to the sprayer, and maintain the sprayer parts in good condition.
- Certain pesticides break down very quickly when left in solution, and several pesticide solutions are corrosive to sprayer parts.
- Sprayer cleaning is especially important when changing from one crop to another or from one pesticide to another. To avoid the risk of contamination, sprayers should be cleaned as soon as possible after application is completed.
- There are different cleanout methods used for different products. If the wrong method is used it may result in crop injury. Refer to the Guide to Crop Protection under Sprayer Cleaning for more information.
- There are different cleanout methods used for different products. If the wrong method is used it may result in crop injury. Refer to the Guide to Crop Protection under Sprayer Cleaning for more information.

Cleanout Methods

The Ammonia Rinse

- Fill the spray tank and add 1L of household ammonia three per cent for every 100 L of clean water needed for the rinse and begin agitation. Allow solution to flush through the booms until the boom is completely filled with ammonia solution and top up the tank with water. Circulate the ammonia solution through the tank and pump system for 15 minutes. Flush hoses and booms with ammonia rinse solution again (minimum five minutes) before emptying. Remove nozzles and screens and scrub with 0.1L household ammonia per 10 L of clean water with an old toothbrush. Perform clean water rinse to remove the ammonia solution prior to the next spray load. Some herbicides recommend leaving the ammonia rinse in the tank overnight to improve cleaning potential.

The Fresh Water Rinse

- The spray tank cleaning should begin and end with a fresh water rinse to remove the majority of potential contaminants prior to the cleansing process or prior to the next round of spraying. Drain the tank of its previous contents and fill the tank with clean water. Open nozzle valves and pump clean water through the booms and hoses. Top up the tank with more clean water and circulate/agitate for at least 10 minutes and empty the tank of waste water. If this is the first rinse after spraying, a high pressure hose could be used to clean residue from all surfaces in the tank.

The Detergent Rinse

- After rinsing with clean water, fill spray tank and add a heavy-duty detergent at 0.25 L per 100 L of water (some suggest a non-ionic surfactant such as Agral 90 or Agsurf at 0.6 L per 100 of water). Circulate the mixture for a minimum of five minutes and spray out through sprayer nozzles. Nozzles and screens are removed and cleaned individually with the same detergent solution in a small container. Soaking in this solution for several hours also helps to loosen any deposits.

Figure 5.55 Sprayer with tank

Special Considerations

- In the case of products that have no cleaning recommendations on the label, there are some basic principles that can be applied:
  - » Products that are water based formulations can usually be cleaned from spray tanks using the fresh water rinse.
  - » Products that are formulated as an emulsifiable concentrate (EC), suspension concentrate (SC) or flowable (F) or use a petroleum based adjuvant should at least use the detergent rinse. The detergent breaks down the oil that may be sticking to the side of the tank.
  - » Products in Group 2 (most will already have a recommendation), with the exception of the 'IMI' products, will require the use of the ammonia rinse. The ammonia either increases the solubility of the product allowing it to be easily removed from the tank surfaces or speeds the breakdown of these products in water.
  - » If the product that is to be cleaned out of the tank is a combination of these elements, use a combination of methods to clean the tank. In these cases, use a good commercial tank-cleaning product from a recognized source, with both ammonia and detergent as components.

Group 2 Cleaning

Group 2 compounds are highly active on sensitive plants so even a small amount remaining in the sprayer can present a risk of injury. They can also occasionally be trapped on the tank walls and plumbing by petroleum based formulations or adjuvants when tank mixed with other products, resulting in tank residues that may be tougher to remove.

- A way to reduce the chance of this occurring is to add detergent at 0.25 L per 100 L to the ammonia rinse portion to assist with the breakdown of the petroleum coating so that the ammonia may rid the tank of the Group 2 product.
- It is important to clean sprayers immediately after every use. With a more diverse rotation, the likelihood of damage from lack of care increases dramatically.

Figure 5.56 Sprayer nozzle

Section 6: Environmental Stresses

It's important to remember that while scouting, there could be multiple issues in a field even if the initial search was only for one. Environmental stress can be confused with other problems and sometimes it can be difficult to distinguish one specific stress over another.

Frost

An early frost can cause damage to crops, especially if plant development is delayed. The extent of frost damage to crops will depend on the temperature, length of exposure time, humidity levels, and how long it takes to reach freezing temperatures. Consequently, it is very difficult to give a definite temperature to which crops can tolerate frost. Information in this section is to be used as a guide only.

The contents of plant cells include not only water but also many substances including proteins, sugars, amino acids and other solutes that can lower the freezing temperature of the cell solution and protect the cells against intracellular ice formation (similar to antifreeze). This means that even though water freezes at 0 C, a plant cell may withstand temperatures down to -4 C or lower before the cells will freeze and cause damage to the plant. Different types of plants will have different susceptibility to freezing temperatures. Levels of the 'antifreeze' compounds depend on the different parts of the plant, stages of development and the plant type.

Damage from frost occurs when moisture in the plant crystallizes and expands causing the walls of the cells to rupture and fluid to leak out. This causes the main symptom of frost damage to be a watery appearance of the plant tissue or seed. Moisture or heavy dew can protect the plant from frost because as the dew changes from liquid to solid (freezes), it gives off heat which can help the plant tissue stay above freezing for a period of time. Once the dew is completely frozen, it will no longer give up energy (heat), eliminating any plant protection. Thus, the duration of the frost is critical.

Spring frosts have the potential to damage germinating seedlings. The severity of the damage depends on the location of the plant's growth point (above or below ground) and the level of 'anti-freeze' compounds in the plant. Exposure to cooler temperatures over time can harden off plants so they are more tolerant of frost. A gradual change in temperature has a lesser effect than a dramatic change in temperature. Environmental conditions such as dry soil conditions or high wind with high evaporation potential can aggravate spring frost injury. Injury can be lessened by moist soils or heavy dews.

Forage Crops

Older alfalfa plants are more susceptible to damage than younger stands. Symptoms of frost damage in alfalfa can include wilting within 24 hours after temperatures down to -3 C, yellowish or brownish discolouration appearing three or four days after the frost, or top stems bending in the shape of "shepherd's hook". Plants will usually recover but development may be delayed, and the yield can be reduced. After temperatures lower than -4 C for over four hours, stems will die, and growing points can be damaged. Alfalfa plants will survive in most cases, but the stand may be weakened if cut before root reserves had time to replenish.

Cereal Crops

The growth point of wheat, barley, rye, and triticale remains at seeding depth until the crown node forms (about the 3-leaf stage). This growth point is deeper than other cereal crops of oats, corn and millet and therefore wheat, barley, rye, and triticale can withstand colder temperatures. Cereals overall are more tolerant to spring frosts than many other crops since the growth point is protected under the soil surface until the 5-leaf or jointing stage. Plants may lose above-ground leaf matter but can regrow from below-ground. Partial injury is visible when the tips of leaves or leaf edges become damaged, yellow and turn brown and brittle. Severe injury is when all above-ground plant matter is damaged and will result in delayed maturity because the plant will need to regrow. Cereals have a good frost tolerance and can survive frosts down to -4 C, if hardened, -6 C.

Winter wheat is at a more advanced stage than other crops in the spring. Although winter wheat survives the cold all winter, once it is green and growing, it is susceptible to frost. Winter wheat is quite tolerant at tillering, tolerating -11 C for up to two hours. Tolerance decreases at stem elongation, handling -4 C for up to two hours. Winter wheat is most sensitive at the boot stage, tolerating -2 C for up to two hours.

**Winter wheat info courtesy of Manitoba Agriculture- Spring Frost Damage Bulletin*

***Corn info courtesy of Manitoba Corn Growers Association - Field Corn Production in Manitoba*

Early season frost in corn will often kill leaves and not the whole plant since the growth point remains below the soil surface until the V6 growth stage. Maturity may be delayed causing an impact on yield.

In situations of fall frost, typically wheat is more tolerant than barley, and barley is more tolerant than oats. Cereal plants exposed to frost at the late dough stage sustain less injury than plants exposed at earlier stages. Plants exposed to frost during the late boot to flowering stage are more susceptible to damage because this is when the reproductive tissue is developing. Barley is more susceptible to frost injury than wheat during the boot stage because it flowers while still in the boot. During the milk stage, temperatures below 0 C can result in shriveled kernels. After the mid-dough stage, temperatures down to -4 C can result in bran frost, kernel shrinkage and possibly a reduction in germination. Frost damage at the milk and early dough stages first appears within a couple of days after the frost as soft, watery kernels that ooze water when squeezed.

Fall frost in corn, before physiological maturity (black layer or R6), can have a negative impact on both grain yield and quality. A killing frost (at least -2 C) any time prior to R6 will kill the entire plant, stopping kernel development. If the frost is not a killing frost, and the leaves/stalks are still green two to five days later, grain filling will continue until maturity (the crop will still need necessary heat units to fully mature following the delay).

Figure 6.1 Frost damage on wheat

Figure 6.2 Frost damage on rye heads

Figure 6.3 Fall rye with sterile spikelets (white) due to frost

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.4 Cold injury on cereals

Oilseeds

Newly emerged canola seedlings at the cotyledon stage can be very susceptible to spring frost as the growth point is above ground. Canola plants at the three to four leaf stage are much more tolerant and can withstand a couple more degrees of frost. Typically, canola can tolerate temperatures down to -4 C, hardened plants can withstand temperatures to -7 C and potentially lower. A light frost that burns the leaves may not injure the growing point. If there is regrowth or green material at the growth point, then the plants may recover (Figure 6.5). Typically, it will be three to seven days before damage can be assessed. There can be damaged and undamaged plants near each other within the field. To determine the viability, check to see if the growth point is green (green regrowth should be visible after four to ten days) and if the stems are still healthy. Severely damaged plants will pinch off at the top of the stem and the whole seedling will brown off.

Figure 6.5 Frost damage on canola

Courtesy of: Saskatchewan Crop Insurance Corporation (SCIC)

Flax is quite sensitive to frost when it is coming out of the ground. Temperatures of -2 C or colder can injure flax up to the two-leaf stage. As flax grows, it becomes more tolerant to frost. After the two-leaf stage, flax can tolerate temperatures down to -7 C and slightly lower if the plants are hardened off. Frost canker can be an issue with flax during early stages of growth, reducing the stand up to 50 per cent. Symptoms of frost canker occur when plants become girdled at or near the soil line and topple over. Damage from frost canker is the most severe in thin stands on light soils and in low spots of the field.

Mustard seedlings are more tolerant of late spring frosts than canola and flax seedlings.

In terms of fall frost, the pods and flowers of canola and mustard will freeze before the leaves. The leaves can tolerate -3 to -4 C while the flowers and developing pods can be affected by -2 to -3 C. Immature seeds containing 50 to 60 per cent moisture can be severely damaged from -3 C frost but seeds closer to swath timing (35 per cent moisture) can escape damage. To escape most frost damage, the moisture content should be at least 20 per cent or lower. Frost at flowering will delay maturity but only cause minor reductions in yield due to flower abortion. Flowers that are open are the most vulnerable.

Swathing at least 24 hours (preferably 48 to 72 hours) prior to a frost can reduce the green seed count, even during early maturity stages such as zero to five per cent seed colour change. At 30 to 40 per cent seed colour change, temperatures of -3 C for one hour will have no effect on chlorophyll content. As temperatures reach -7 C, the effect on chlorophyll content will be much greater. Swathing the crop 48 hours prior to -7 C will reduce the chlorophyll content compared to leaving the crop standing.

Once frost occurs, it is important to assess the extent of damage to canola. Assess the field (damage vs. undamaged seeds) two to three days after frost or later. If most of the seed is damaged, swath the crop immediately. If not, leave the crop to develop to the proper swathing stage. If the crop has frozen and the pods turn white, swath immediately as the pods will begin to shatter.

Figure 6.6 Frost damage on flax

Pulses

Lentils and peas have good frost tolerance as their growth points remain below ground during early development. The above ground material may be severely injured by frost, but new growth will resume from the lower or below ground nodes within a week to 10 days following a frost. Light frost on newly emerged seedlings will cause damage to the oldest leaves that are encasing the younger leaves and the growing point.

**Spring frost in soybean information courtesy of Manitoba Agriculture – Spring Frost Damage Bulletin*

Soybean plants just coming through the soil surface up to the cotyledon stage can tolerate -3 C for a few hours. The smaller the soybean plant, the more tolerant they are to frost. Soybeans exposed to frost at the cotyledon stage may leaf out again. Check for signs of regrowth after three to five days. At the cotyledon stage, soybeans have three potential growth points consisting of the main shoot and two axillary buds located at the base of the cotyledons. Under normal conditions, the axillary buds never grow, but if the main point is killed by frost, the two axillary buds will start to grow within a week following the frost. During the summer, one of the axillary branches will become dominant and be the main stem of the soybean plant.

Fall frosts of -2 to -3 C will affect flowering pulses. In the podding stage, they are a bit more tolerant but will be damaged at -3 to -4 C. Frost damaged seeds will be water soaked and no longer be firm as they start to "leak". Heavily damaged pods will have a rubbery, wilted appearance. As pulses mature from the bottom up, frost injury may be much greater at the tops of the plant. Seeds near the ground may have no frost damage and care should be taken to focus harvest efforts on those seeds.

**Fall frost in soybean information courtesy of Manitoba Pulse Growers – Impact of Fall Frost on Soybean Factsheet*

Soybean yield will be impacted by fall frosts if the soybeans have not reached physiological maturity. A light fall frost (0 to -1 C) may kill top leaf growth but should not affect pods and seeds. Temperatures below -1 C for an extended period of time will cause damage to green stems, pods and seeds, reducing yield and quality. Maximum yield loss would occur if soybeans are in the reproductive stage.

Figure 6.7 Frost damaged peas

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.8 Frost damaged peas

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.9 Frost damaged peas

Figure 6.10 Fall frost on soybeans

Figure 6.11 Frost damage on lentils

Figure 6.12 Frost damaged faba bean

Courtesy of: Saskatchewan Pulse Growers

Figure 6.13 Frost damaged faba bean

Courtesy of: Saskatchewan Pulse Growers

Hail

Hail damage and recovery depend on the stage and type of crop. Crops with growing points below ground are likely to regrow, although maturity may be delayed. It is advisable to give the crop a few days before assessing whether reseeding is necessary, as plants may recover on their own. However, the open wounds caused by hail can provide an access point for bacterial infections, as many bacterial pathogens rely on open wounds to invade plants. While fungal pathogens typically do not require a wound to infect plants, they can also enter through openings caused by hail damage. Increases in fungal disease activity after a hail event may be more likely due to a humid environment that promotes fungal growth or the rain and hail splashing pathogen-infected soil onto plant surfaces.

Cereal Crops

Hail injury to wheat typically results from stem breakage, with the greatest yield losses occurring when the stems are broken at the milk stage. Yield losses may not be as severe if the injury happens at the boot stage. At the hard dough stage, yield loss can be highly variable and may not be as extreme as the damage that occurs at the milk stage. In corn, hail damage is easy to identify, as the leaves are shredded and the stalks may be bruised. Early-season hail, when the growing point is still below the soil surface, will result in very little yield loss. However, if hail occurs later in the season, the yield loss may be significant. It is recommended to wait seven to 10 days after a hail event before assessing the damage so that living and dead plant tissue can be more easily distinguished.

Figure 6.14 Hail damage to wheat

Figure 6.15 Hail damage to wheat in boot stage

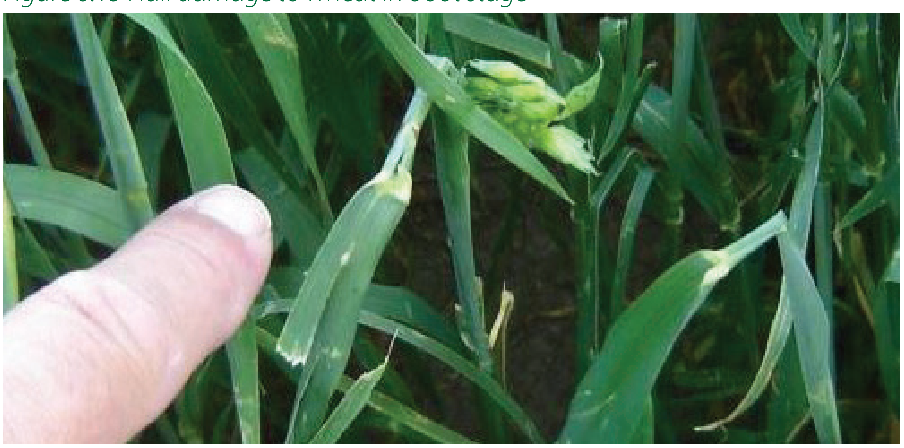


Figure 6.16 Hail damage to wheat

Figure 6.17 Hail damage on corn

Figure 6.18 Hail damage on durum

Figure 6.19 Hail damage in fall rye

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.20 Hail damage in fall rye

Courtesy of: Saskatchewan Crop Insurance Corporation

Oilseeds

**Information courtesy of Canola Council of Canada's Canola Watch*

Early-season hail is not as common, and seedlings that are hailed on can often recover quite well. However, if hail breaks the cotyledons or damages the stem, these plants typically do not survive. Despite this, the crop can still recover its yield potential as the remaining seedlings benefit from reduced competition for light, moisture and nutrients. This allows the plants to grow larger, produce more branches, and develop more pods and seeds per pod, compensating for the lost plants. However, having fewer plants can result in delayed and uneven maturity across the field, which can present challenges for fungicide application timing and harvest timing.

Hail that occurs later, when the plants are at the four to six-leaf stage, carries a higher chance of yield loss due to the reduced time for recovery. Plants at the six-leaf stage that lose most of the leaf area on the main stem can still survive, but these leaves will not regrow. As a result, plant growth is delayed, and yield potential will largely come from side branches. Crops hailed on at the four to six-leaf stage or earlier can also be more susceptible to blackleg. If the field was already at high risk for blackleg, hail damage can increase that risk. Additionally, hail can cause seeds inside pods to bruise, which may lead to premature pod shatter.

Figure 6.21 Hail damage on canola

Figure 6.22 Hail damage on canola

Figure 6.23 Hail damage on canola

Figure 6.24 Hail damage on canola

Figure 6.25 Hail damage on canola stems

Figure 6.26 Hail damage on canola stem

Figure 6.27 Hail damage on flax

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.28 Hail damage on flax

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.29 Hail damage on flax

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.30 Hail damaged flax stem

Figure 6.31 Normal flax seed

Figure 6.32 Hail damage to immature flax seed

Figure 6.33 Hail damaged flax seed

Pulses

**Pulse information courtesy of Saskatchewan Pulse Growers- Environmental Damage to Pulses Factsheet*

Early-season hail damage to peas, lentils, faba beans, and chickpeas has an impact similar to frost damage. These plants will continue to develop from dormant buds within one or two weeks, so it is advisable to delay reseeding assessments to allow time for the crop to recover. However, hail damage to the growing point of dry beans and soybeans at early stages can severely limit recovery. While damage to soybeans at the vegetative stage can tolerate a fair amount of leaf loss without significant yield loss, damage to the growing point at earlier stages can have a much more detrimental effect on the crop's ability to recover.

Figure 6.34 Hail damage on pea plant

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.35 Hail damage on pea field

Figure 6.36 Hail damage on pea field

Figure 6.37 Hail damage on pea

Figure 6.38 Hail damage on soybean

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.39 Hail damage on soybean stem

Figure 6.40 Damage on soybean field one month after hail event

Courtesy of: Saskatchewan Crop Insurance Corporation

Moisture

Drought Stress

Drought stress results from a prolonged period of dry weather, leading to water shortages during plant development. It is considered a major limiting factor in the productivity and growth of crops on the prairies, as it reduces root proliferation, vegetative growth, and ultimately, final yield. In response to drought stress, plants undergo morphological and physiological changes to combat water loss. For example, plants may reduce stomatal conductivity to slow water loss. However, this also decreases the photosynthetic rate within the plant. As water loss from plant tissues increases, the turgidity of the tissues is reduced, leading to leaf rolling and wilting. Drought stress is closely linked with high-temperature stress. Plants typically cool themselves through evapotranspiration, so when water is in short supply, crops are more susceptible to high-temperature stress as well.

Excess Moisture

**Information courtesy of Manitoba Agriculture – Managing Crops for Excess Water Stress*

Excess moisture in the soil can lead to oxygen deficiencies, which in turn reduce the plant's ability to take up essential nutrients. The tolerance of crops to waterlogging depends on several factors, including soil type, plant species, growth stage, temperature, day length and the duration of the stress. In the short term, plant roots and shoots can adapt to reduced oxygen levels by lowering respiration rates and slowing the growth of shoots. However, prolonged exposure to excess water can create symptoms similar to those experienced by crops under dry conditions. Crop tolerance to excess water varies across different species. Below is a general guide to the relative tolerance of common crops to excess moisture, although tolerance may vary depending on environmental factors and growth stages of crops.

Cereals: oats > wheat > barley

Pulses: faba beans > soybeans > field beans > peas/lentils

Oilseeds: canola > sunflower > flax

Forages: grasses > legumes

- Reed canarygrass > timothy > orchardgrass > perennial ryegrass
- Birdsfoot trefoil/red clover > alsike clover > sweet clover > alfalfa

Cereals

Drought Stress

In wheat, as moisture stress intensifies during the later tillering stages, the potential for yield recovery decreases. This is due to both a reduction in the number of kernels per spikelet and diminished filling upon recovery. If drought stress intensifies as the plant continues to develop, established tillers may be lost. Additionally, moisture stress can reduce the size of the developing spikes. Dry soil around the crown also impedes the plant's ability to develop adventitious roots, which are essential for accessing water and nutrients as the plant grows beyond the seedling stage. High temperatures in wheat reduce grain yield and its components, and a reduced number of kernels per spike can serve as an indicator of moisture or heat stress. High temperatures and moisture stress in oats during panicle differentiation can lead to empty florets, with tillers generally being more affected than the main stems (culms).

In corn, dry conditions cause the leaves to roll and turn a dull greyish green, while nitrogen deficiency symptoms may appear in older plants. Severe stunting and irregular brown patches of dead leaf tissue may also occur. Symptoms of moisture deficiency in corn that disappear as the temperature drops are often caused by high temperatures, which are especially problematic early in the growing season when root development is insufficient. While permanent bleaching and scalding of leaf tissue are rare, high temperatures and drought during pollination can lead to sterility and barren ears.

Excess Moisture

Waterlogging will cause young plants to turn yellow and eventually die. Older plants can stand water-logged conditions for a longer period, but they will also become yellow, weak, and susceptible to disease after a week.

Figure 6.41 Moisture stress damage to oats with heat blasting

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.42 Adequate moisture vs dry area in a field

Figure 6.43 Drought on durum

Figure 6.44 Drought stress on durum

Figure 6.45 Sun-scalded wheat

Figure 6.46 Durum damaged by extreme dry conditions

Courtesy of: Saskatchewan Crop Insurance Corporation

Figure 6.47 Moisture stress on fall rye

Oilseeds

Information courtesy of Canola Council of Canada's Canola Watch

Drought Stress

Lack of moisture during the reproductive stages of canola can lead to a hormone imbalance, which disrupts pod formation and seed set. During periods of low moisture, canola plants will flower prematurely and can then begin to drop flowers from the top of the main raceme and on branches, redirecting energy towards preserving the pods that have already formed. A lack of moisture later in the season, particularly during pod fill, can result in seeds that fail to form or may even germinate within the pod due to this hormone imbalance. If moisture returns, plants may start producing flowers again, but this often results in a stem with pods at the bottom and top, with no pods in the middle. Additional symptoms of moisture stress in canola include leaf wilting, flowers with smaller petals that may appear pale or yellowish-orange, and flower buds that die before they fully open.

Excess Moisture

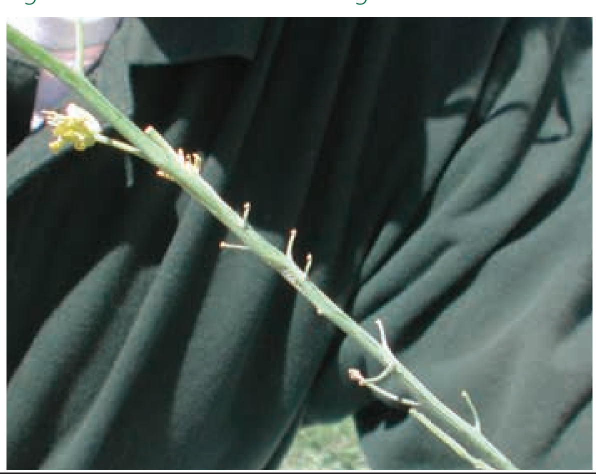
The tolerance of oilseed crops to excess moisture depends on multiple factors, including the growth stage of plants. A few days of waterlogged soils can be enough to kill young canola seedlings resulting in total yield loss. Both canola and flax are more sensitive at younger growth stages and become more tolerant as they age. Canola plants that have been stressed because of excess moisture may bolt or flower prematurely resulting in reduced yields.

Figure 6.48 Early flowering canola (June 28) due to dry conditions

Figure 6.49 Moisture stress (heat) damage to flax

Figure 6.50 Blasting in canola due to extreme dry conditions

Figure 6.51 Canola floret blasting



Pulses

Drought Stress

Moisture stress during the vegetative stage of dry beans can lead to delayed maturity. This stress also results in a decrease in the number of pods per plant and the number of seeds per pod. Indeterminate genotypes of dry beans, which have a longer flowering period, typically produce more pods under intermittent moisture stress compared to determinate types with shorter flowering periods. Root growth in dry beans is also vulnerable to moisture stress, and unlike shoot growth, root development is less responsive to re-watering after the plant has experienced moisture stress. Chickpeas, on the other hand, are relatively tolerant to moisture stress due to their long taproot, often extending beyond one metre in depth, which allows them to access water from greater depths than other pulse crops. However, chickpeas are most sensitive to moisture stress during specific stages, including flowering, pod production, and seed set. In soybean, heat stress can cause copper discolouration on the leaves, a condition that is noticeable as the leaves take on a distinct, altered colour.

Figure 6.52 Waterlogged peas

Excess Moisture

Peas and lentils are sensitive to waterlogging or excessive moisture, which can result in poor growth and decreased leaf area. This excess moisture can also cause accelerated leaf senescence or necrosis, decreased transpiration and water uptake, and flower drop. Furthermore, excess moisture in peas and lentils may lead to root rot development. See the disease section for more information.

Summary

In summary, drought and excess moisture can both significantly affect crop productivity, each causing unique challenges for plant growth. Drought stress, caused by prolonged dry weather, leads to water shortages during plant development, reducing root proliferation, vegetative growth, and overall yield. As drought stress progresses, it can result in wilting, leaf rolling, and reduced turgidity. Drought stress is also closely associated with high-temperature stress, as plants become more vulnerable to heat when water is scarce. In contrast, excess moisture can cause oxygen deficiencies in the soil, reducing the plant's ability to take up nutrients. Waterlogging can result in symptoms similar to drought stress, including yellowing, wilting, and root rot, especially in crops like peas, lentils, and young canola seedlings. Various crops show different tolerances to excess moisture, with cereals generally more tolerant than oilseeds and pulses.

Figure 6.53 Heat (sunburn) damage on soybean leaf

Courtesy of Saskatchewan Crop Insurance Corporation

Figure 6.54 Drought damage on soybean

Figure 6.55 Peas damaged by extreme dry conditions

Figure 6.56 Peas damaged by extreme dry conditions

Wind

**Information courtesy of Canola Council of Canada's Canola Encyclopedia and Saskatchewan Pulse Growers- Environmental Damage to Pulses Factsheet*

High winds can cause many issues for crops. Wind can contribute to physical plant injury, lodging, yield loss, and an increased presence of diseases. Physical plant damage can be caused by blowing material, such as sand and other debris, which can harm young crops and provide a pathway for disease. Wind stress to seedlings is often referred to as "wind whipping" or "sandblasting" and can occur in any crop. Seedlings that are completely severed may regrow, but this can delay plant maturity. Fully mature crops may experience lodging or seed loss, as the wind can topple a dense canopy. Dry conditions can exacerbate losses, as the plants may be weaker, and the stems may break completely.

Areas more likely to be affected by wind include hilltops, fields with lighter soils, or regions with minimal windbreaks. To reduce wind damage, shelterbelts or windbreaks can be used. A zero-till farming operation can also reduce wind damage by allowing the crop to remain covered by stubble in the early growing stages.

Figure 6.57 Sandblasting on soybeans

Soil Crusting

Soil crusting can occur in the spring after seeding and before crop emergence and cause challenges with crop emergence. Sudden heavy rainfall can cause soil crusting as raindrops break apart soil aggregates that realign in a denser configuration. This can result in emergence issues in the spring if the crop hasn't already broken through. Canola or pulses can send out multiple shoots attempting to break through the crust, which can sometimes be mistaken for insect damage.

Land rolling may cause soil crusting if heavy rain occurs after rolling and before crop emergence. Soil with high organic matter and crop residues is less prone to crust over. The amount of soil crusting that occurs depends on several factors, including soil texture, organic matter, and amount of crop residue on the soil surface. More crop residue will help prevent soil crusting and soil erosion.

The best solution for soil crusting is to maintain zero-till practices that allow standing stubble and crop residues to remain on the soil surface, especially after seeding. The residue will soften the impact of raindrops, increase soil organic matter, and improve soil structure over time. Improving soil structure will help prevent soil crusting in the future.

Possible in-season solutions to soil crusting may be to give the field a gentle harrow or to use a rotary hoe if available. It's good to do a short pass or two and assess if the harrowing is doing more damage than good. More aggressive harrowing can cause damage to larger seedlings. In worst-case scenarios, reseeding may be necessary if the crop is unable to breach the surface.

Figure 6.58 Soil crusting and poor crop emergence caused from sudden heavy rainfall

Smoke

In recent years, there has been growing interest regarding the potential impact of wildfire smoke on Saskatchewan crops, given the regular occurrence of Canadian wildfires. While this topic has not been well-researched, there is evidence to suggest that wildfire smoke may have both positive and negative impacts on crop growth.

- Potential Positive Impacts
  - Reduce heat intensity by diffusing direct sunlight and increasing penetration of solar radiation into inner plant canopy.
  - Reduce evaporation of soil moisture
  - Increased ozone levels can inhibit some bacterial and fungal spread.
  - Trigger plants to produce thicker waxy cuticle that allows them to be better endure drought conditions.
- Potential Negative Impacts
  - Reduce sunlight and increase ozone levels which can potentially lead to reduced photosynthesis.
  - High levels of ozone can cause bronzing or bleaching of upper leaf surfaces.

The effect of smoke will also depend on many variables including crop type, crop stage, proximity of the crop is to the fire, how thick the smoke is, and duration of the smoke cover.

Source: https://agcrops.osu.edu/newsletter/corn-newsletter/2023-21/how-could-haze-wildfires-affect-crop-growth https://crops.extension.iastate.edu/blog/mark-licht-sotirios-archontoulis/wildfire-smoke-impacts-crop-production#:~:text=There%20are%20both%20positive%20and,weaker%20and%20susceptible%20to%20lodging.

Figure 6.59 Wildfire smoke

Section 7: Harvest

Estimating Yield Prior to Harvest

The procedure used to estimate yields prior to harvest starts by first determining the number of seeds per square metre in representative parts of the field. These are then used to arrive at an average number of seeds per square metre and converted to kilograms per square metre. For this calculation the number of seeds per kilogram must be known or estimated. The kilograms per square metre is then converted to kilograms per hectare by multiplying by 10,000. A harvest loss factor is applied to reflect seeds that may not be captured or retained during the harvest operation. This is expressed as a percentage loss. The appraisal yield is in kilograms per hectare and can be converted to bushels per acre.

Different crop types require a slightly different approach to determining the seeds per square metre. These procedures are described in the specific sections for pulses, canola and cereals.

Peas, lentils, faba bean, dry beans and soybean

Once pods are developed, count the number of pods per square metre instead of plants. Multiply by an average number of seeds per pod determined by counting the number of seeds per pod on five plants in a row and dividing by the number of plants. At this time, also determine the number of plants in a square metre. There should be at least three counts per field of less than 20 acres and up to 12 counts in 160 acres. More or less counts may be required depending on crop uniformity. To complete the calculations, you can use the thousand kernel weight (TKW) from the SK Varieties Guide or if crop is physiologically mature use a seed sample from the field to determine the seed weight. Harvest loss factors may be applied depending on crop, field-crop condition and harvest equipment.

Below is an example for a pre-harvest yield appraisal on yellow peas. In this example the harvest loss was estimated at 10 per cent.

Yellow peas example

Crop	Yellow peas-CDC Amarillo-TKW 230 g = 4350 seeds/kg				
Sample#	Pods Per Square Metre		Seeds Per Pod		Seeds per Square Metre
1	276	X	4	=	1104
2	329	X	3.5	=	1151.5
3	335	X	4.2	=	1407
4	385	X	4	=	1540
5		X		=	
			Total seeds	=	5202.5
			Divided by number of counts	divide	4
			Average seeds per square metre	=	1300.6
			Seeds/kg by variety	divide	4350
			kgs seed per square metre	=	0.3
			Square metres per hectare	X	10000
			Yield kg/ha	=	2990 kg/ha
			Less harvest loss (100-10% loss) ÷ 100	X	0.90
			APPRAISAL kg/ha	=	2691 kg/ha
			Conversion to bu/ac	X	0.01487
			Imperial yield bu/ac	=	40 bu/ac

Canola

Canola is a one of the more difficult crops to assess yield, especially if the stand is not uniform. Pull out all the plants in a square metre and categorize them in big, medium and small plants. Count the number of pods on a representative plant from each category and multiply by the respective number of plants in that category. Don't count miss-formed and small pods, nor the top ones on the side branches. To determine the number of seeds per pod, count number of seeds in five to 10 pods for each category and arrive at an average number of seeds per pod for each category. Be sure to include mainstem and side branch pods.

Here is an example for a pre-harvest yield appraisal on hybrid canola.

Hybrid canola example

L252, TKW = 3.2 g (do not use the TKW number on the seed bag for yield calculations as this will greatly over-estimate the yield).

Crop	Canola: L 252 TKW 3.22 g = 310000 seeds/kg						
Sample#	Plants Per Square Metre		Pods Per Plant		Seeds Per Pod		Seeds Per Square Metre
1a	6	X	165	X	25	=	24750
1b	22	X	62	X	24	=	32736
1c	12	X	12	X	18	=	2592
Total 1	40						60078
2a	10	X	187	X	24	=	44880
2b	19	X	74	X	25	=	35150
2c	18	X	11	X	18	=	3564
Total 2	47						83594
3a	5	X	198	X	24	=	23760
3b	34	X	87	X	26	=	76908
3c	4	X	9	X	12	=	432
Total 3	43						101100
Average					Total of sites	=	244772
					Divided by number of counts	divide	3
					Average seeds per square metre	=	81591
					Seeds per kg	divide	310000
					kgs seed per square metre	=	0.2632 kg/m^2
					Square metres per hectare	X	10000
					Yield kg/ha	=	2632 kg/ha
					Less harvest loss (100-5% loss) ÷ 100	X	0.95
					APPRAISAL	=	2500.4 kg/ha
					Conversion to bu/ac	X	0.01785
					Imperial yield bu/ac		44.6 bu/ac

Cereals

In cereals, count the number of heads per square metre. For every count, pull five to 10 consecutive plants in a row and rub out the kernels. Divide the total number of kernels by the number of heads to get average number of kernels per head.

Here is an example for a pre-harvest yield appraisal on durum, Strongfield, 43g TKW .

Durum example

Durum wheat, Strongfield, TKW = 43 g

Crop	Durum Strongfield; 43g TKW = 23300 seeds/kg						
Sample#	Plants Per Square Metre		Heads Per Plant		Seeds Per Head		Seeds Per Square Metre
1	251	X	1	X	24	=	6024
2	237	X	1	X	23	=	5451
3	268	X	1	X	25	=	6700
					Total seeds	=	18175
					Divided by number of counts	divide	3
					Average seeds per square metre	=	6058
					Seeds per kg	divide	23300
					kgs seed per square metre	=	0.2600 kg/m^2
					Square metres per hectare	X	10000
					Yield kg/ha	=	2600
					Less harvest loss (100-2% loss) ÷ 100	X	0.98
					APPRAISAL	=	2548.1 kg/ha
					Conversion to bu/ac	X	0.01487
					Imperial yield bu/ac		37.9 bu/ac

Pre-Harvest Interval

Pesticide labels refer to the pre-harvest interval (PHI). This is the minimum number of days that you must let pass from applying a product until the crop is swathed or straight-cut. It may also be referred to as the Spray to Swath Interval. It is important to follow PHI guidelines to ensure the maximum residue limit (MRL) for a pesticide is not exceeded. The PHI applies not only to field crops but forages as well. PHIs have been established for fungicides, insecticides, and herbicides. By following the established PHI, you are protecting the marketability of your crop and in the case of forages, the animals which ingest the crop. The PHI will be found on the pesticide label and is referred to for each pesticide in the Guide to Crop Protection.

To help time applications, or choose a product that fits a timeline, canola and pulse growers can use the interactive Keep it Clean Spray to Swath Interval Calculator found at ***spraytoswath.ca***.

Pre-Harvest Information

What are desiccants?

Desiccants are contact herbicides that interfere with photosynthesis, causing plant cells to rapidly break down and release their liquid contents to dry down more rapidly. True desiccants rely heavily on penetration and canopy coverage. Higher water volumes and nozzles that provide good coverage will maximize their performance.

What are pre-harvest aids?

Glyphosate is not a desiccant. It is a systemic herbicide that is absorbed and translocated within actively growing plants to kill them. It does not aid in crop dry down since preharvest applications are restricted to after the least mature areas of the crop are less than 30 per cent seed moisture content. At this point the crop is no longer actively growing. This is designed to prevent translocation within the crop that could limit market access. Preharvest applications are intended for perennial, winter annual and biennial weed control.

When and why to apply desiccants

When applying desiccants, timing is important. Incorrect timing of pre-harvest herbicides can negatively affect crop maturity and can impact market accessibility. Desiccants applied too early can interfere with the process of seed filling, resulting in yield loss. This application should only be applied once the grain moisture is less than 30 per cent in the least ripe part of the field.

Pre-harvest desiccation may reduce the time from maturity to threshing readiness and reduce shatter loss. Desiccation may also result in improved quality if the crop is harvested before being exposed to wet weather compared to a crop left to mature on its own. Standing crop will dry more rapidly compared to swaths following a rainfall. This can save time when waiting for harvest to resume. Using a desiccant can help minimize late disease development and harvest problems caused by late weed growth, uneven ripening of crops and crop lodging. Individual circumstances will determine if desiccation provides financial and operational benefits.

When timing the application, make sure the crop stage is correct, use recommended product rates and surfactants, if required, and use proper water volumes. Be ready to combine as soon as the dry down is complete to maximize yield and quality.

Refer to the Guide to Crop Protection, Herbicides for Use as Harvest Aid or Desiccant Before Crop Harvest to help decide what herbicide to use before harvest.

Choosing the right product

If choosing to use chemical assistance at the time of harvest, consideration should be given to how the grain will be marketed and whether it will be used for human consumption or animal feed. Discussion with the intended grain buyer as to what pre-harvest products are allowed based on the commodities end use may help avoid rejection at the time of delivery. There may also be special considerations if the grain is going to be used for seed.

Keep it Clean is a great resource for producers to use in order to help with product decisions for their field. They help outline the market risks to producers when choosing certain crop protection products.

Maximum Residue Limits (MRLs)

A maximum residue limit (MRL) is the highest amount of pesticide residue that may remain on or in food when a pesticide is used according to label directions. In Canada, MRLs are legal and enforceable limits set for the different combinations of pesticides on foods or crops. In other countries, maximum residue limits may be referred to as maximum residue levels, or tolerances, and can vary from one country to another. This variation between countries is a key reason why it is important to follow PHI and pesticide labels. This helps to avoid disrupting or jeopardizing any export opportunities, since the MRL values of the importing countries must also be met.

It is important to note that MRLs are not safe consumption limits. MRLs are set significantly lower than what is safe for consumption. The initial phase in establishing an MRL involves conducting safety tests. However, the safety margin for an MRL is typically several hundred times higher than the level at which any potential risk could occur.

Harvest Do's and Don'ts

There are many ways to help ensure that the quality and reputation of Canadian crops helps keep the markets open for all:

1. In each crop ensure only pesticides registered for that crop in Canada are applied. Contact the intended grain buyer to confirm pesticide use acceptability for domestic and export buyers.

2. In addition, always read and follow the label for application rate, timing and pre-harvest intervals (PHI). Applying unregistered pesticides or desiccants is illegal and may result in unacceptable residues.

3. Manage disease pressures by developing an integrated disease management plan. Diseases such as blackleg and fusarium head blight can create a market risk, so make sure to grow disease-resistant varieties when available. Consider applying an appropriately timed fungicide when disease risk is high and plan crop rotations to manage diseases. Plant clean seed and use seed treatments under high-risk conditions. Control volunteer plants, weeds, and other susceptible disease hosts.

4. Grains should be properly stored to maintain quality and keep them free of harmful cross-contaminants such as blood meal and bone meal. Only use approved bin treatments and never use malathion to treat bins that will be used to store canola. Canola should not be stored in facilities that have been recently treated with malathion. Condition grain to moisture and temperature levels safe for long-term storage. In addition, keep bins clean, dry, and well-ventilated. Check on filled bins frequently to prevent problems later.

5. Deliver what is declared and ensure that any updated Declarations of Eligibility are reviewed before delivering grain or making contracts. Signing a mandatory Declaration of Eligibility affidavit at the elevator, is a legal assertion that the crop is the variety and/or class that has been designated and that it was not treated with crop input products not specified in the declaration. Any incorrect information, intentional or unintentional, can be traced back to the farm and individuals can be held liable for any costs associated with contamination of a bin or shipment. In addition, always make sure to only grow registered varieties.

Adapted from:
Government of Canada
Keep It Clean! Resources to Grow Market-Ready Crops
url: www.keepitclean.ca

Swathing

There are several key points to consider when deciding to swath or straight cut. Swathing may be an option in scenarios where there is uneven maturity in the field due to variable plant emergence, field topography, soil type and soil moisture. It hastens dry-down if there are proper drying conditions in the swath. Producers may not want to risk losses due to shattering while waiting for later maturing areas of the field to dry down. Swathing also helps to reduce shatter losses during harvest, particularly for crops with a higher tendency to shatter, such as six-row barley. It also offers a strategy to deal with lodging and terminates under-story growth such as late flushes of tillers, volunteers, and weeds. Weather conditions also need to be considered if swathing is the best harvest method. If swaths are exposed to heavy rain or dew, this can affect grain quality due to sprouting, staining, and disease build-up compared to a standing crop.

All considerations should be weighed, and fields should be assessed just before the optimal swath timing for the given crop.

Table 7.1 Optimal swath timing

Crop	Stage
Wheat	Kernel moisture content is 35% or less
Barley (malting)	Kernel moisture content is below 30%
Canola	An average of 60% seed colour change on the main stem
Flax	75% of bolls or capsules have turned brown
Lentils	The bottom third of the pods turn yellow to brown and rattle when shaken
Peas	The bottom 30% of pods are ripe, the middle 40% of pods and vines are yellow-coloured, and the upper 30% of pods are turning yellow
Chickpeas	Can be swathed as early as 30% seed moisture, but is usually left until the majority of pods are straw yellow

Adapted from: Canola Council of Canada-https://www.canolacouncil.org/download/157/canola-encyclopedia/4900/canola_swathing_guide

Staging Pre-Harvest Applications of Herbicides

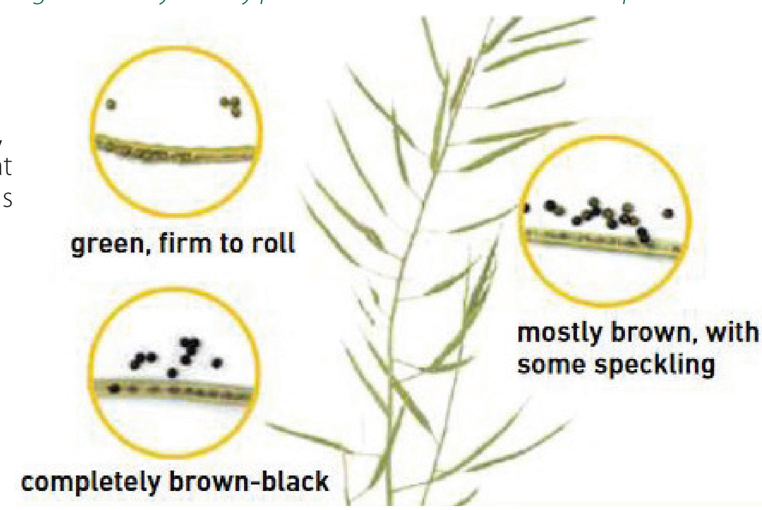
The appropriate application stage is when the crop is at physiological maturity (30 per cent seed moisture or less). Pesticide products can lead to higher residues in the seed and reduced yields when applied too early. Know the proper staging for harvest aid products and ensure the entire area being sprayed is at the recommended stage.

It is important for producers to check with their grain buyers to ensure that there are no market risks prior to applying pre-harvest herbicides prior to applying pre-harvest herbicides and to consult product labels for proper use instructions and warnings. ***Keep it Clean*** is a great resource for producers to use in order to help with product decisions for their field. They help outline the market risks to producers when choosing certain crop protection products.

Canola

Canola must be desiccated at the correct stage to avoid locking in green seed. If fields have variable stages, the stage that will contribute most to total yield should be determined. Canola seeds mature in the bottom pods first, while seeds in the top pods mature last. When using diquat brands, ideal application timing is after 90 per cent of seeds on the entire plant have turned brown. Saflufenacil should be applied when 65-80 per cent of seeds have changed colour. Applying desiccants earlier than recommended may result in higher green seed counts and reduced yields. If harvest is delayed following desiccation of canola, both pod drop and pod shatter may increase. Combine when seed moisture has reached suitable levels, which can happen anywhere between four to 14 days post application.

Figure 7.1 Fifty to sixty per cent seed colour on a canola plant



Courtesy of: Keep It Clean Canada

Figure 7.1 shows what 50-60 per cent seed colour change looks like on a canola plant. The bottom third of the plant is completely black/ brown. The middle third is brown, with some speckling. The top third can be green but must be firm when rolled. When scouting for seed colour change you must step into the field and open pods up. Pods may look green but could have brown-black seeds inside.

Chickpeas

Glyphosate

Apply pre-harvest glyphosate to chickpeas when plants have yellowed, the pods have matured, and seeds have changed colour and detached themselves from the pods (pods rattle).

Diquat

The majority of plants are yellow, pods mature, seeds changed colour and detached from pods.

Saflufenacil

Desi: Apply when most seeds turn yellow or brown

Kabuli: apply when most seeds turn white or tan

Figure 7.2 Chickpea staging for pre-harvest glyphosate

Courtesy of: Saskatchewan Pulse Growers

Dry Beans

Glyphosate

Apply pre-harvest glyphosate to dry beans when the crop has lost 80-90 per cent of leaves and 80 per cent of pods are yellow. Seeds have lost their green colour when split.

Diquat

Crop has lost 80-90 per cent of leaves and 80 per cent of pods are yellow.

Saflufenacil

Stems are green to brown, pods are mature (they are yellow to brown) and 80-90 per cent of leaves have dropped.

Figure 7.3 Dry bean staging for pre-harvest glyphosate

Courtesy of: Saskatchewan Pulse Growers

Faba Beans

Glyphosate

Use pre-harvest glyphosate when stems are green to brown in colour; pods are mature (yellow to brown in colour); 80-90 per cent leaf drop (original leaves).

Diquat

Most plants are ripe and dry. Pods fully filled, bottom pods are tan or black in colour. (Except *Nufarm Drifast* and *Innovis Diquat 240 Harvest Aide*)

Saflufenacil

Apply when 80 per cent of lower pods have turned black, middle pods have turned yellow/tan, and top green pods have firm seed. (Only *Heat LQ*)

Field Peas

Glyphosate

For proper pre-harvest glyphosate timing, Ensure the field has turned to a yellow-brown colour with green patches. Ensure that 80 per cent of the plant is yellow to brown in colour, and that bottom pods are ripe and dry with seeds detached from the pods, producing a rattling sound when moved. The middle third of the pea plant should have seeds that are yellow, full sized, firm, and seeds split when squished. Top pods should be wrinkled with firm seed. The top of the plant may have a slight green colour.

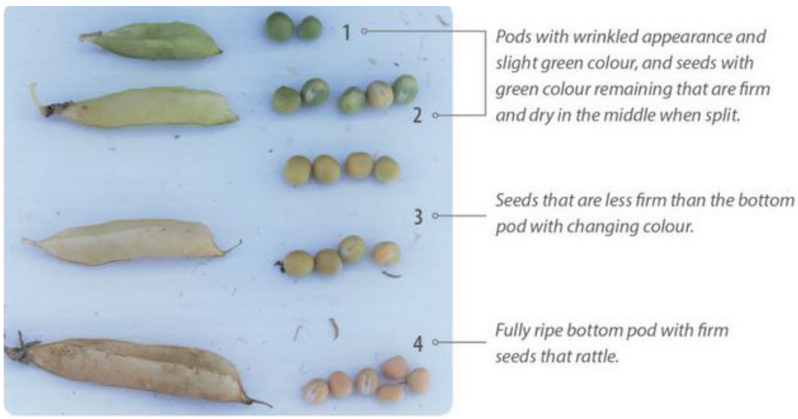
Diquat

Use diquat when bottom pods are ripe and dry, and seeds are detached from pods.

Saflufenacil

Apply when the majority of the pods are brown (70-80 per cent).

Figure 7.4 Field Pea seed and pod colour change progression



Courtesy of: Saskatchewan Pulse Growers

Figure 7.5 Pea field staging for pre-harvest glyphosate

Courtesy of: Saskatchewan Pulse Growers

Flax

Variable plant staging within the same crop can make pre-harvest chemical application at the proper stage extremely challenging and reinforces the importance of rating the maturity of flax crops accurately.

- Seed of brown-seeded varieties changes from pale green to yellow with brown tips and then to brown as it matures. Yellow-seeded varieties turn from pale green to pale yellow with darker yellow tips to a darker yellow colour.
- As the seed inside the boll matures, the colour of the boll changes. Bolls will change from green to yellow and finally to brown during the maturation process.
- Flax is considered physiologically mature when 75 per cent of the bolls (in the field or on a plant) are brown and the boll segments have begun to separate. This is a visual rating that corresponds to a grain moisture content of around 30 per cent and is known as 75 per cent boll turn or 75 per cent brown boll stage.
- The shade of brown can greatly differ between flax varieties so it is important to also look for boll segment separation.
- Flax is ready to be swathed or desiccated or have pre-harvest glyphosate applied when physiologically mature because seed quality and yield will not be compromised at this stage of the crop's lifecycle.
- When a crop consists of plants of multiple growth stages, a pre-harvest chemical should not be applied until the latest maturing plants reach physiological maturity, or alternatively the late maturing patches within the field can be avoided and then sprayed later when at the appropriate stage.
- Flax is ready to be combined when 90 to 100 per cent of the bolls are brown. Seed will rattle loudly in the bolls and the moisture content will be 10 per cent or less. Bolls will easily crush with fingers and seed should easily rub out of bolls.

Courtesy of: Manitoba Crop Alliance, Flax Council of Canada and Sask Flax

Soybeans

Glyphosate

Apply pre-harvest glyphosate when stems are green to brown in colour and pod tissue is brown and dry in appearance (80-90 per cent leaf drop).

Diquat

Use diquat when the crop has lost 80-90 per cent of leaves and 80 per cent of pods are yellow.

Saflufenacil

Apply when stems are green to brown, pods are mature (yellow to brown), and 80-90 per cent of leaves have dropped.

Wheat

Glyphosate

At lower than 30 per cent grain moisture, the easiest way to determine if a wheat crop is ready for a pre-harvest application of glyphosate is the thumbnail test. Put a reasonable amount of pressure from your thumbnail into the kernel and if it leaves a dent without splitting it is ready. This is known as the hard dough stage. After application, harvest is typically seven to 14 days away.

Saflufenacil

Hard dough stage, Zaddoks growth stage of 87. Lower than 30 per cent seed moisture.

Figure 7.6 Thumbnail test for wheat

Courtesy of: Keep It Clean Canada

Lentils

Glyphosate

The lentil field should have an 80 per cent colour change of tan, brown. Pods on bottom third are brown with hard seeds detached from pod that rattle when shaken. Pods in middle third have seeds that are full size and firm showing 100 per cent colour change from light green to tan-brown. Top third of plant will show 50-75 per cent colour change and may have slight green colour, but seeds are fully formed and firm.

Diquat

Use diquat when the lowest pods are light brown and rattle when shaken.

Saflufenacil

Red lentils only. Lowermost pods (15 per cent), and rattle when shaken. Glyphosate must be added when applying *Heat* pre-harvest in red lentil varieties. Stand alone applications of *Heat* are not registered on red lentil varieties.

Figure 7.7 Pre-harvest glyphosate application staging

Courtesy of: Keep It Clean Canada

Moisture Content

Moisture content is the percentage of water in the grain. The moisture content of grain at harvest is important for future quality and safe storage. When a grain sample is within acceptable moisture limits it is considered straight grade. As moisture content increases, it is considered tough, damp, moist, or wet.

The Canadian Grain Commission determines moisture content using a Unified Grain Moisture Algorithm (UGMA) moisture meter. They provide calibrations for a 919/3.5", or equivalent, moisture meter model. Additional information, conversion tables, and calculators can be found on the Canadian Grain Commission's website.

The following table shows the tough and damp moisture content of common crops. Moisture levels below the lowest tough percentage are considered straight grade and within acceptable moisture limits. It should be noted that dockage within the sample can influence moisture content.

Table 7.2 Tough and damp moisture content in common crops

	Moisture Ranges		
Grain	**Straight (%)**	**Tough (%)**	**Damp (%)**
Barley (feed)	< 14.9	14.9-17.0	> 17.0
Barley(malt)	< 13.6	13.6-17.0	> 17.0
Canary seed	< 13.1	13.1-17.0	> 17.0
Canola and Rapeseed	< 10.1	10.1-12.5	> 12.5
Chickpeas	< 14.1	14.1-16.0	> 16.0
Corn	< 15.6	15.6-17.5	17.6-21.0
Faba beans	< 16.1	16.1-18.0	> 18.0
Flaxseed	< 10.1	10.1-13.5	> 13.5
Lentils (green)	< 14.1	14.1-16.0	> 16.0
Lentils (red)	< 13.1	13.1-16.0	>16.0
Mustard (all classes)	< 9.6	9.6-12.5	> 12.5
Oats	< 13.6	13.6-17.0	> 17.0
Peas (green and yellow)	<16.1	16.1-18.0	> 18.0
Rye	< 14.1	14.1-17.0	> 17.0
Soybeans	< 14.1	14.1-16.0	16.1-18.0
Sunflower	< 9.6	9.6-13.5	13.6-17.0
Triticale	< 14.1	14.1-17.0	> 17.0
Wheat (all classes)	< 14.6	14.6-17.0	> 17.0

Adapted from: Canadian Grain Commission-https://grainscanada.gc.ca/en/grain-quality/grain-grading/grading-factors/moisture-content/tough-damp-ranges.html

** Percentage wet weight basis. Courtesy of: Canadian Grain Commission 2005*

Drying Down Tough Grain for Seed

If you are planning on drying grain during the fall or winter that you intend to use for seed next spring, it is crucial that the grain temperature is kept at or below the maximum safe temperature as shown in Table 7.3. Grain that reaches temperatures above this can have a negative impact on the germination of the seed and overall viability. If temperatures have exceeded the safe temperature or heating has occurred in the bin, then it is important to determine what per cent is damaged and alter the seeding rate accordingly to accommodate for these damaged seeds. This can be done by testing seed for germination and vigour rates. If the damage is too high, other seed source options should be considered. It is important to keep drying temperature in mind if planning on using harvested grain as seed the following year.

More information on the safe temperatures and moisture contents of grains can be found on the Canadian Grain Commission website. If your grain is at risk of spoilage, conditioning it using a grain dryer can be important to help reduce the risk of spoilage.

Table 7.3 Maximum safe air drying temperatures (C) for grain to be used as seed

Commodity	Seed or Malting	Commercial Use	Feed
Wheat	60	65	80-100
Oats	50	60	80-100
Barley	45	55	80-100
Rye	45	60	80-100
Corn	45	60	90-100
Flax	45	80	80-100
Canola	45	65	N/A
Peas	45	70	80-100
Mustard	45	45	N/A
Sunflowers	45	50	N/A
Buckwheat	45	45	N/A
Lentils	45	N/A	N/A
Soybeans	43	49	N/A

Table information based on "Heated-Air Grain Dryers", Pub 1700, Agriculture and Agri-Food Canada, Canadian Grain Commission recommendations and Saskatchewan Pulse Growers.

Preventing Spoilage

Temperature and moisture content of the grain has a large impact on the ability to store grain long-term over the winter months following harvest. Grain that is taken off with a higher moisture content, or considered tough, has a risk of spoilage during storage. There is also potential for hot spots to develop in storage bins from things such as moulds, fungi, insects, plant material, and oxidation. These hot spots can cause areas of heated seeds that will lower the germination as well. A drop in germ, possible insect infestation, and/or grain heating may result if temperature and moisture are not kept in safe ranges. Grain at straight grade moisture percentages does not guarantee long-term safe storage. Consult the safe storage charts on the following pages for proper temperature and moisture to keep grain at for long-term storage.

How to use Safe Storage Charts:

- Measure the moisture content and temperature of your crop as it goes into storage.
- Plot this initial moisture content and initial temperature on the chart. If the result falls in the no spoilage zone, then your crop should store safely for up to five months, six months in the case of wheat. If it falls in the spoilage zone, spoilage can occur sooner.
- Cool or dry the crop in storage until the temperature or moisture content is in the no spoilage zone.
- The centre zone accounts for a one per cent safety margin, although spoilage may occur under these conditions.
- Be aware that the moisture content and temperature of stored grain may change during storage due to convection currents, leading to localized spoilage. Monitor the top-centre of the bin regularly throughout storage or use aeration.

Comprehensive Natural-Air-Grain-Drying (NAD)

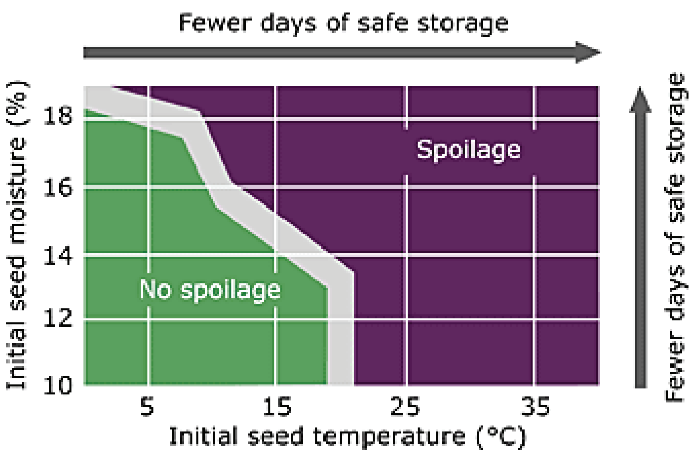
Adapted from PAMIs Comprehensive Natural-Air-Grain-Drying (NAD) Factsheet

Safe Storage Time and Target Moisture Contents for Common Crops

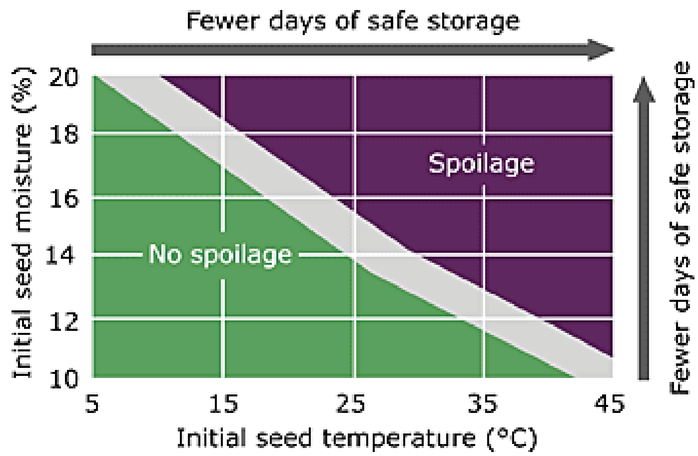
The main concern when storing grain is to avoid spoilage. Microorganisms responsible for spoilage thrive in hot and moist conditions, so both temperature and moisture content must be properly managed. The below charts outline relative safe storage times for several crops, including target temperatures and moisture contents.

Note: "no spoilage" should be interpreted as "reduced risk of spoilage" as these are guidelines only.

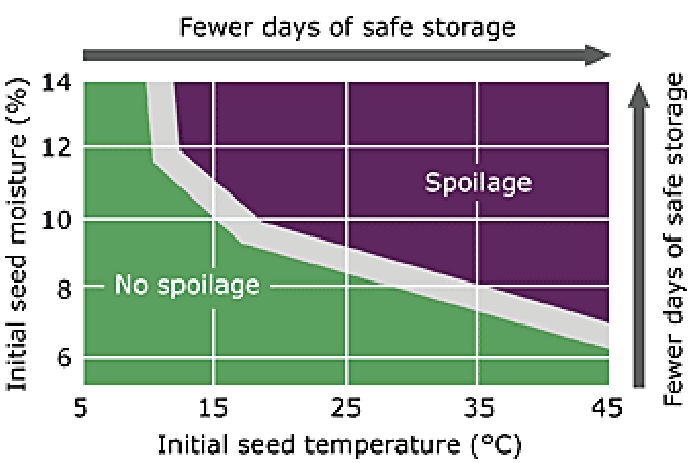
Safe Storage Chart for Barley



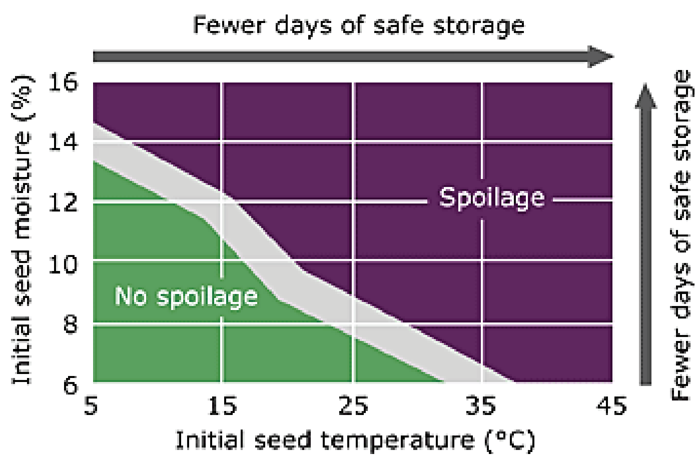
Safe Storage Chart for Dry Beans



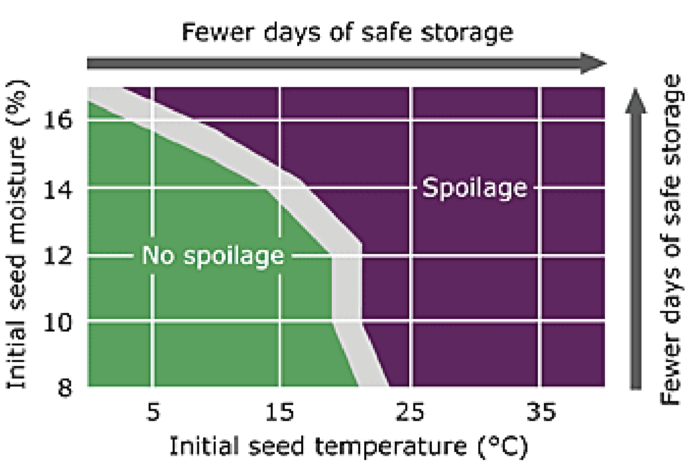
Safe Storage Chart for Canola



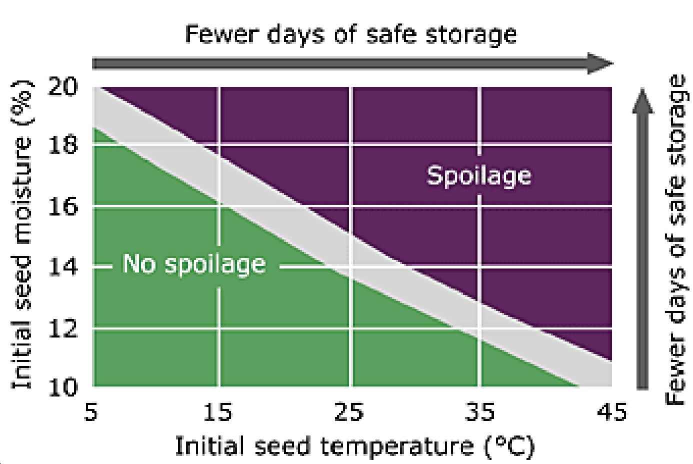
Safe Storage Chart for Flax



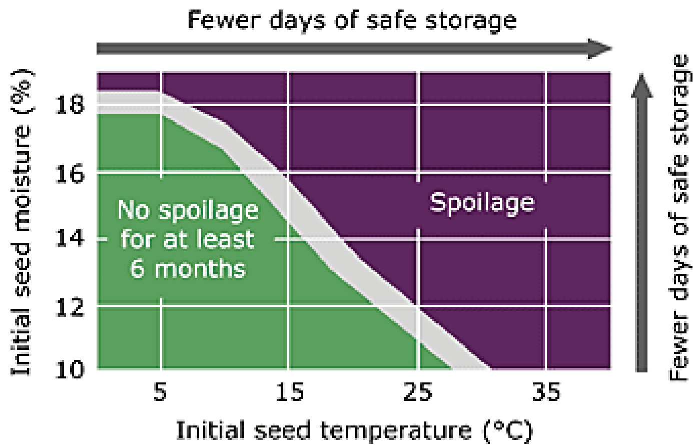
Safe Storage Chart for Oats



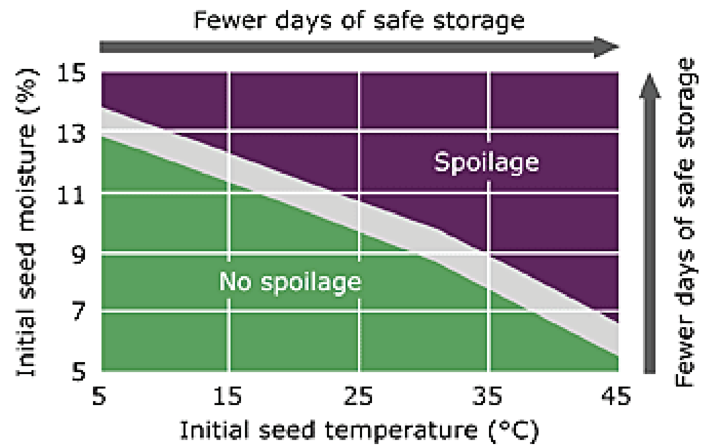
Safe Storage Chart for Peas



Safe Storage Chart for Wheat



Safe Storage Chart for Mustard



Charts reproduced courtesy of: Dr. Noel White, Agriculture and Agri-Food Canada, Cereal Research Centre, as posted on the Canadian Grain Commission website.

Management Strategies for Controlling Temperature and Moisture

There are multiple strategies for controlling temperature and moisture in-bin. The table below will help you determine which management strategy will work best for your operation's needs.

	Description	Pros	Cons
Aeration	Cools and create an even temperature profile Low airflow rates (0.1 cfm/bu)	Minimal capital investment "Better than nothing"	No moisture control
Natural Air Drying (NAD)	In-bin moisture and temperature control Grain will dry if the ambient air has a "capacity to dry" (page 8) Blows ambient air (5-25 C) through grain Uses moderate air flow rates (approx. 1 cfm/bu)	Energy savings Smaller investment Reduced risk of spoilage Most suitable when ambient >15 C	Slow (can take weeks) Requires management Success dependent on ambient conditions
NAD with Supplemental Heat	Adding heater to a NAD fan to increase the temperature of the air going into the bin	Turns a "poor" drying day into a "good" drying day Minimal capital investment Most suitable when ambient >0 C Reduces drying time	Requires management (and grain turning) Few options for temperature control Energy cost
Heated Air Drying	Usually a small batch process Uses hot air (45-85 C) to dry grain Uses very high air-flow rates (approx. 20 cfm/bu)	Success does not depend on ambient conditions Dries grain quickly (hours) Suitable for any ambient condition	Can result in seed damage Requires cooling cycle High capital and energy costs

NOTE: cfm/bu = cubic feet per minute per bushel

How to Use Airflow Resistance Charts for Managing Stored Grain

Airflow resistance in a grain bin is an important measure as it dictates how much airflow (cubic feet of air per minute, or cfm) your fan is pushing into the grain. The target airflow for aeration (cooling) is 0.1 to 0.25 cfm per bushel while the target airflow for natural air drying is 0.5 to 1 cfm per bushel. Note that airflow rates between 0.25 and 0.50 cfm per bushel will result in faster cooling or conditioning, and may also result in some moisture loss or removal (depending on air and grain conditions).

Resistance to airflow depends on:

- Grain Type (size of voids):
  Smaller seeds = smaller voids = increased resistance to airflow
- Depth of the Grain:
  Greater depths = greater resistance to airflow
- Fan Speed:
  The faster the fan tries to push air through grain, the greater the resistance to airflow
- Type of Distribution System (ducting):
  More restrictive ducting systems/plenums may increase the total airflow resistance (data not available for direct comparison).

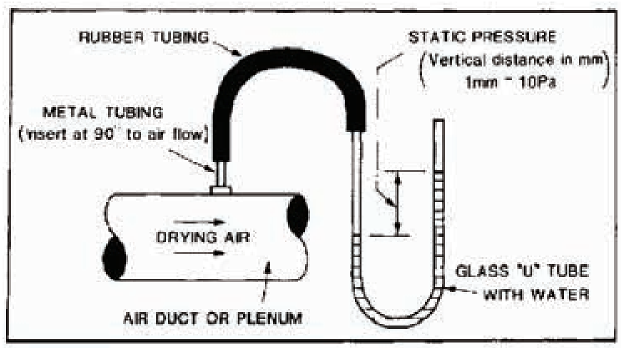
Airflow resistance is measured in static pressure (inches of H20) and is dependent on grain type and depth. As grain depth increases, airflow resistance increases (and airflow rate decreases).

There are two applications (described later) for using airflow resistance to know or predict airflow rate:

1. For existing fans, use static pressure and fan curves to estimate the airflow rate in the bin.
2. For new bins, use the resistance-to-airflow charts to determine the fan type and size that will achieve the desired airflow rate.

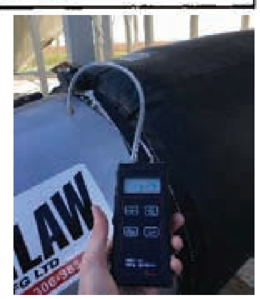
How to Measure Static Pressure

Use a static pressure gauge (types below) and install at the fan outlet.



Water Manometer:

- Connect a flexible, transparent tube (minimum inside diameter 1/4 in.) to the transition duct.
- End of tube inside – 90 C to airflow.
- End of tube outside – attach to manometer.
- The difference in water height in inches = static pressure (inches H2O).



Analog manometer (left)

- Specialty gauges will even convert the airflow resistance to an airflow rate for a certain bin/fan size.

Digital manometer (right)

- More expensive, but easier to move from bin to bin.

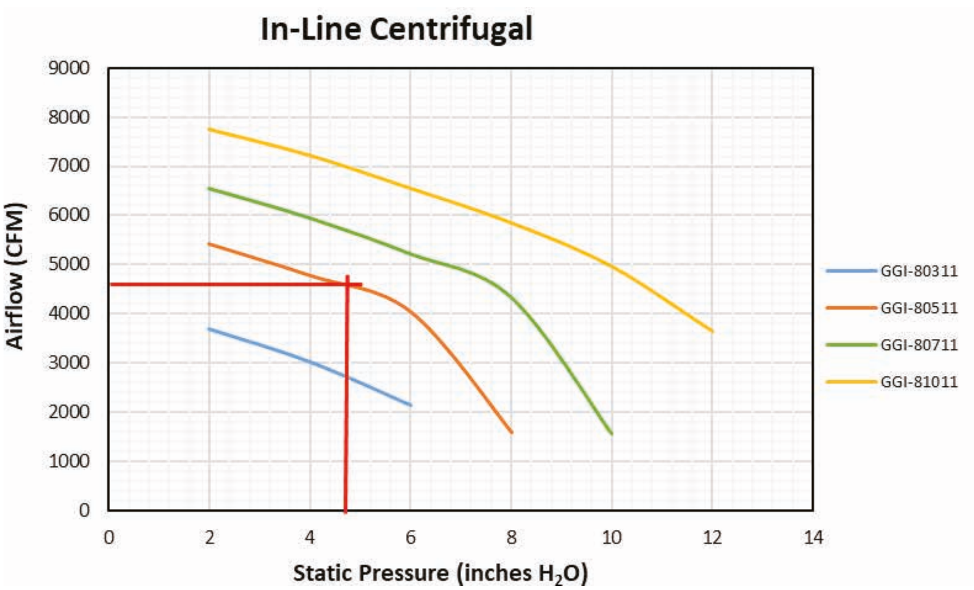
Estimating Airflow Rate in an Existing Bin

To determine the airflow (cfm) from an existing fan, install a static pressure gauge in the aeration ducting near the fan. With the bin full (or at the target grain level) turn on the fan and take the static pressure reading on the pressure gauge. The static pressure will change based on grain depth and grain type. Use the manufacturer's fan performance tables or curves (examples included below for Grain Guard's in-line centrifugal fans), to estimate the airflow rate based on the static pressure reading.

Example: The static pressure reading is 4.6 inches H2O for a 5 hp in-line centrifugal grain guard fan (GGI-80511). In Table 1 at 4 inches H20, the airflow is 4,790 cfm and at 6 inches H20 it is 4,050 cfm. From that it is estimated the airflow is likely around 4,600 cfm.

Table 1. Estimated airflow rates (cfm) for fan models based on static pressure

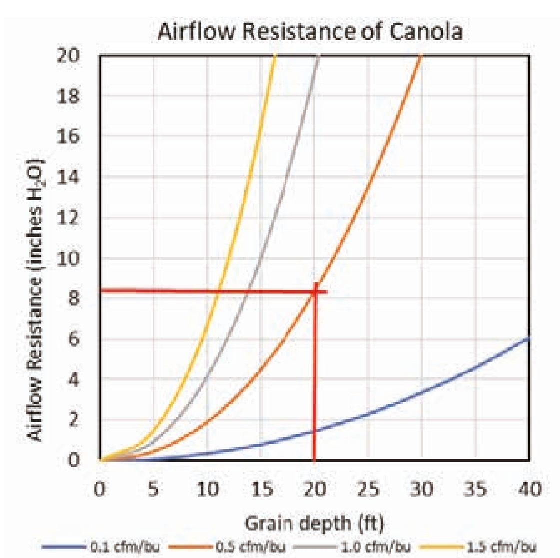
In-Line Centrifugal		Static Pressure (inches H_2O)					
Model	**HP**	**2**	**4**	**6**	**8**	**10**	**12**
GGI-80311	3	3690	3020	2130	0	0	0
GGI-80511	5	5430	4790	4050	1600	0	0
GGI-80711	7	6550	5950	5220	4340	1560	0
GGI-81011	10	7750	7220	6550	5850	4960	3640



Manufacturer-supplied fan information can also be provided in the form of an airflow-static pressure curve (left); these charts make the fan relationships easy to visualize. These charts also show that the airflow rate output is not consistent for all static pressure ranges (ex: GGI-80511).

Selecting the Correct Fan Size for a Desired Airflow Rate

Airflow resistance charts and fan performance tables/charts can be used to estimate the size of fan needed to achieve the desired airflow per volume (0.1 to 0.25 cfm/bu for aeration and 0.5 to 1 cfm/bu. for natural air drying).



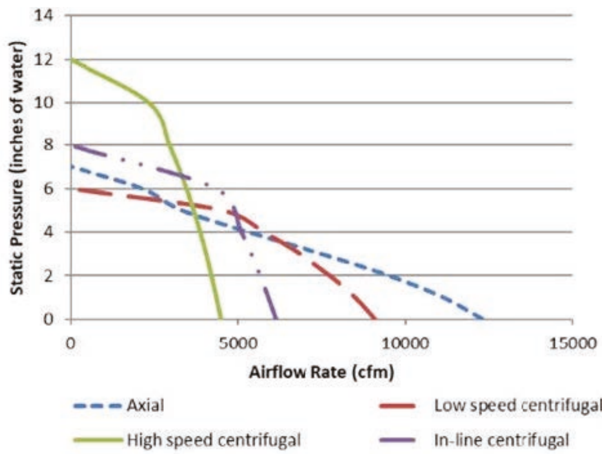
Example: 5000 bushels of canola resulting in a grain depth of 20 ft. The desired airflow is at least 0.5 cfm/bu.

1. Calculate the airflow (cfm) required to achieve 0.5 cfm/bu. 0.5 cfm/bu. x 5000 bu. = 2500 cfm
2. Estimate the airflow resistance using the chart shown (left) for canola. The static pressure on the 0.5 cfm/bu. curve is about 8 inches H20.
3. Use the fan tables or charts to select the appropriate fan. At 8 inches H20, the 5 hp in-line centrifugal fan (GGI-80511) is only producing 1600 cfm, which is less than desired. The 7 hp in-line centrifugal fan (GGI-80711) however, is estimated to produce 4340 cfm which achieves the desired result with airflow of about 0.85 cfm/bu.

Note: These fans are examples only. There may be other fan models or types that are more suitable for this application.

Fan Types

Individual fan models and types have unique airflow ratings, providing the ability to achieve a variety of airflow ranges for different depths of grain. Fan type and size must be selected carefully based on expected static pressure, so make sure you are using the static pressure charts specifically for the type and size of fan you are investigating.



Axial-Flow Fans

Air moves in straight line through the fan parallel to the impeller shaft (supply higher airflows at lower pressures).

Centrifugal Fans

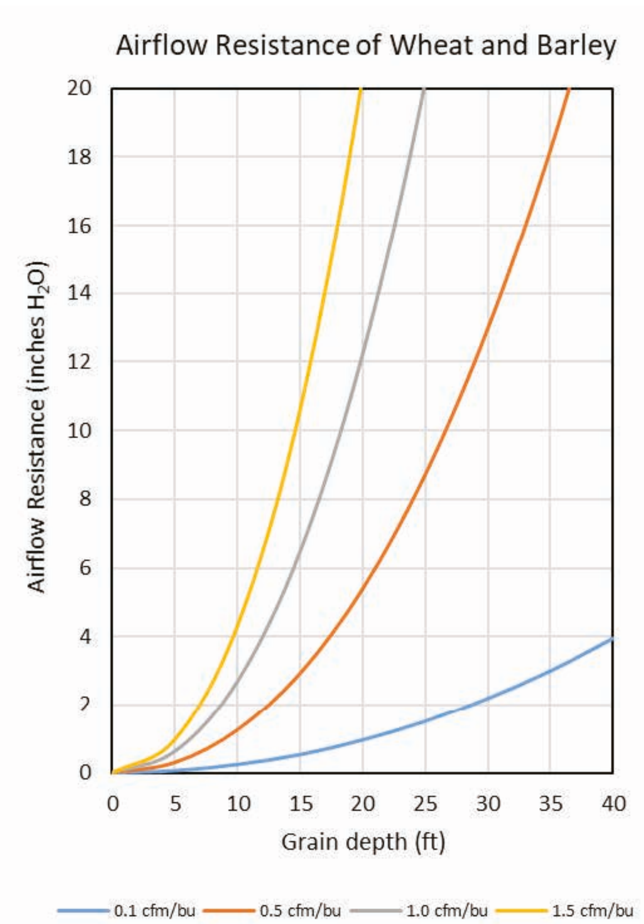
Air enters parallel to the impeller shaft and exits one side perpendicular to the shaft.

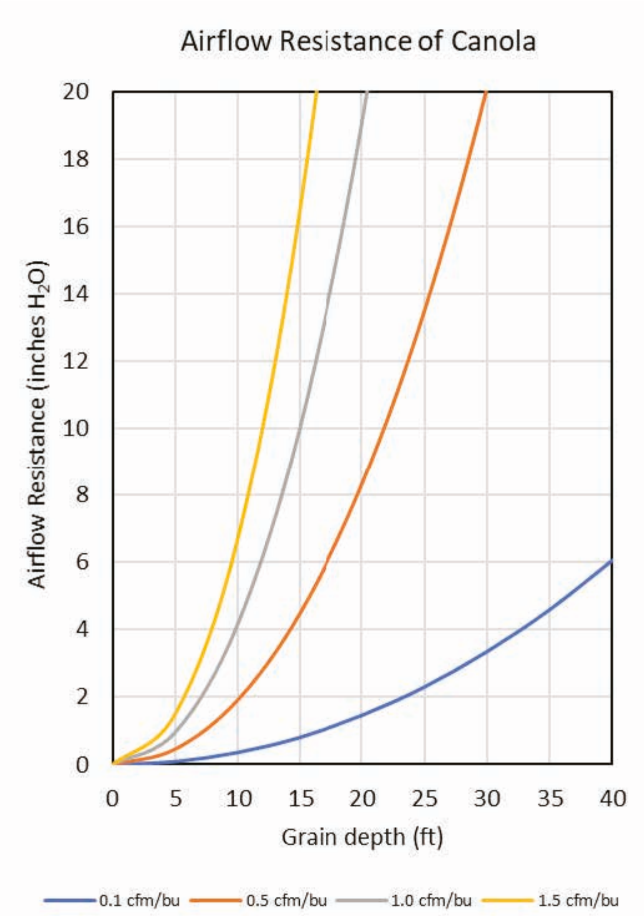
- Low-speed Centrifugal: supply higher airflows at lower pressures.
- High-Speed Centrifugal: supply lower airflows at higher pressures.

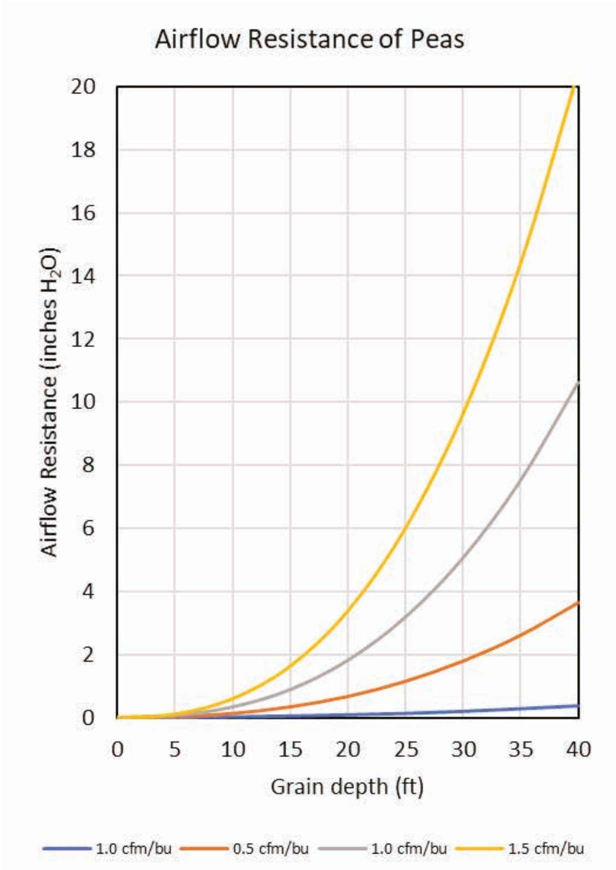
In-Line Centrifugal Fans

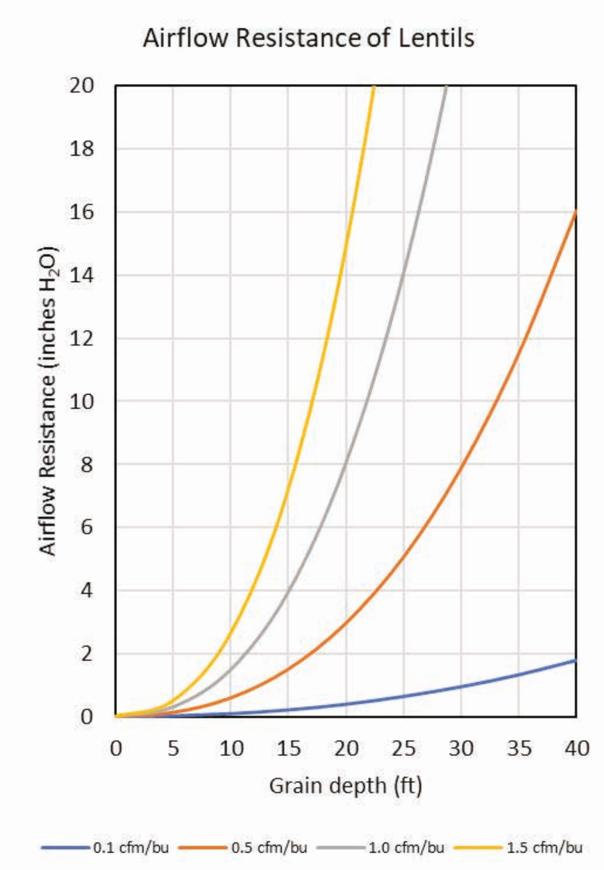
Have axial flow but use a centrifugal type impeller (supply lower airflows at higher pressures).

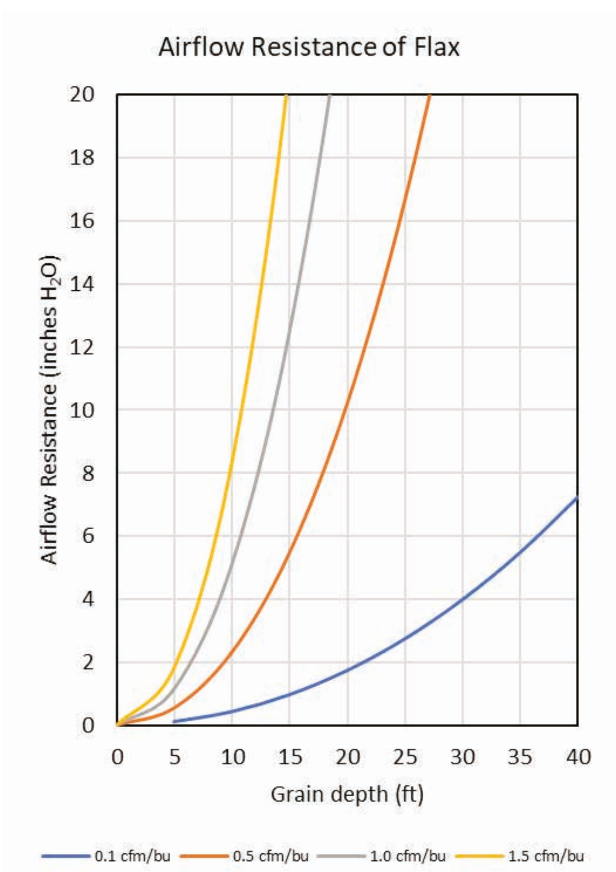
These airflow resistance charts can be used to estimate the expected static pressure based on grain depth, grain type and target airflow rate (cfm/bu). Shedd's model was used to create the charts using experimental data. These charts account for the airflow resistance of the grain only and do not account for added resistance due to chaff, fines, ductwork, or filling method (e.g., grain spreader).

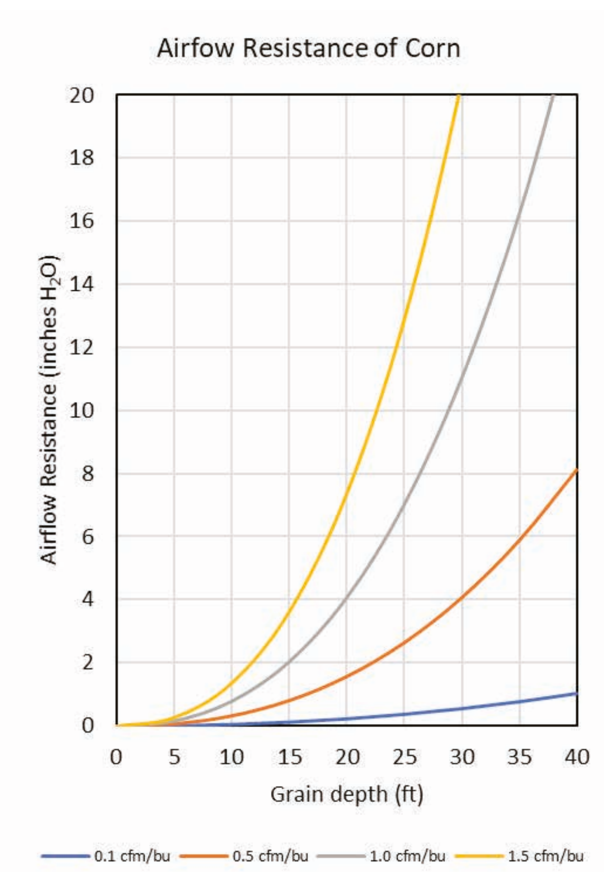





Airflow Resistance of Peas
Airflow Resistance (inches H2O)
Grain depth (ft)
1.0 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Lentils
Airflow Resistance (inches H2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Flax
Airflow Resistance (inches H2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airfow Resistance of Corn
Airflow Resistance (inches H2O)
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu

Equilibrium Moisture Content and Grain Storage Management

The equilibrium moisture content (EMC) of air can be used to predict how the ambient air used for natural air drying (NAD) will affect the moisture content of grain. The EMC of the air depends on its temperature and relative humidity (RH) as well as the grain type. The EMC represents the moisture content that the grain will eventually equilibrate to if the air conditions remain constant for a length of time. The air has a "capacity to dry" when the EMC of the ambient air is less than the moisture of the grain. Although air conditions are rarely constant for longer than an hour, the EMC information can still be used to determine the air temperature and relative humidity ranges that will achieve drying.

Example: If the ambient air has a temperature of 10 C and a RH of 60 per cent, the EMC of the air for WHEAT is 13.6 per cent (refer to EMC chart below). That means that if the air conditions stay constant at 10 C and 60 per cent RH, wheat would eventually equilibrate to 13.6 per cent moisture content (and 10 C). If the goal is to dry wheat to 14.4 per cent, the most effective time to run the fan would be when the EMC of air is less than 14.4 per cent Those conditions (air temperature and RH) are highlighted in red in the chart below.

Temp	Relative Humidity (%)						HARD RED SPRING WHEAT				
(°C)	35	40	45	50	55	60	65	70	75	80	85
-2	10.7	11.4	12.0	12.7	13.5	14.2	15.0	15.9	16.9	18.0	19.3
2	10.4	11.1	11.8	12.5	13.3	14.0	14.8	15.7	16.7	17.8	19.1
5	10.3	11.0	11.7	12.4	13.1	13.9	14.7	15.5	16.5	17.6	19.0
8	10.1	10.8	11.5	12.2	13.0	13.7	14.5	15.4	16.4	17.5	18.9
10	10.0	10.7	11.4	12.1	12.9	13.6	14.4	15.3	16.3	17.4	18.8
13	9.9	10.6	11.3	12.0	12.7	13.5	14.3	15.2	16.2	17.3	18.7
15	9.8	10.5	11.2	11.9	12.6	13.4	14.2	15.1	16.1	17.2	18.6
18	9.6	10.3	11.0	11.8	12.5	13.3	14.1	15.0	16.0	17.1	18.5
22	9.4	10.2	10.9	11.6	12.3	13.1	13.9	14.8	15.8	16.9	18.3
26	9.3	10.0	10.7	11.4	12.2	12.9	13.8	14.6	15.6	16.8	18.2
28	9.2	9.9	10.6	11.3	12.1	12.8	13.7	14.6	15.6	16.7	18.1

It is also important to manage grain temperature as well as moisture content to help prevent spoilage. If you are using warm air (temperature greater than 15 C) to help dry grain, the grain will also warm to that temperature. Once the target moisture content has been reached, aerate with cool air to bring the average grain temperature below 15 C. Due to the effect of grain temperature on the air's ability to remove moisture, this cooling period will also result in some moisture loss, so cooling can start once the grain is within approximately half a per cent of the target moisture content.

Also note that if the grain temperature is considerably different than the air temperature, the EMC of the air will be difficult to determine until the temperature of the air and grain equalizes (usually within 6 to 24 hours of fan operation, depending on airflow rate).

The EMC of air depends on the grain type as well as the air temperature and RH.

Equilibrium Moisture Content Charts for Grain Storage Management

These charts are based on the moisture isotherm data summarized in the ASABE Standard D245.5 (Moisture Relationships of Plant-based Agricultural Products) and various published studies (listed after the charts). Much of the information in ASABE Standard D245.5 is based on research conducted in the 1980s and 1990s. Since that time, plant breeding has resulted in different starch and oil contents of grains and oilseeds which may affect the EMC values. **Therefore, these charts should be used as a guideline only.**

Temp	Relative Humidity (%)				HARD RED WINTER WHEAT (Modified Oswin)						
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	10.0	11.0	12.0	13.2	14.3	15.6	17.1	18.8	20.8	23.2	26.5
5	9.9	10.8	11.9	13.0	14.1	15.4	16.9	18.5	20.5	23.0	26.2
8	9.7	10.7	11.7	12.8	14.0	15.2	16.7	18.3	20.3	22.7	25.9
10	9.6	10.6	11.6	12.7	13.8	15.1	16.5	18.1	20.1	22.5	25.7
13	9.5	10.4	11.4	12.5	13.6	14.9	16.3	17.9	19.8	22.2	25.4
15	9.4	10.3	11.3	12.4	13.5	14.7	16.1	17.7	19.6	22.0	25.1
18	9.2	10.2	11.2	12.2	13.3	14.5	15.9	17.5	19.4	21.7	24.8
22	9.0	10.0	10.9	11.9	13.0	14.2	15.6	17.2	19.0	21.3	24.4
26	8.9	9.8	10.7	11.7	12.8	14.0	15.3	16.8	18.7	20.9	24.0
28	8.8	9.7	10.6	11.6	12.6	13.8	15.1	16.7	18.5	20.7	23.7

Temp	Relative Humidity (%)						**DURUM WHEAT** (Modified Oswin)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	8.7	9.6	10.5	11.5	12.6	13.7	15.0	16.6	18.4	20.6	23.6
5	8.6	9.5	10.4	11.4	12.4	13.6	14.9	16.4	18.2	20.4	23.4
8	8.5	9.4	10.3	11.3	12.3	13.4	14.7	16.2	18.0	20.2	23.2
10	8.4	9.3	10.2	11.2	12.2	13.3	14.6	16.1	17.9	20.1	23.0
13	8.4	9.2	10.1	11.0	12.1	13.2	14.5	15.9	17.7	19.9	22.8
15	8.3	9.1	10.0	11.0	12.0	13.1	14.4	15.8	17.6	19.8	22.7
18	8.2	9.0	9.9	10.8	11.8	13.0	14.2	15.7	17.4	19.6	22.4
22	8.1	8.9	9.7	10.7	11.7	12.8	14.0	15.4	17.1	19.3	22.1
26	7.9	8.7	9.6	10.5	11.5	12.6	13.8	15.2	16.9	19.0	21.8
28	7.9	8.7	9.5	10.4	11.4	12.5	13.7	15.1	16.8	18.9	21.7

Temp	Relative Humidity (%)						**CANOLA/RAPESEED** (Modified Henderson)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	6.4	7.0	7.7	8.4	9.1	9.9	10.7	11.6	12.5	13.6	14.9
5	6.1	6.8	7.4	8.1	8.8	9.5	10.3	11.1	12.0	13.1	14.3
8	5.9	6.5	7.1	7.8	8.5	9.2	9.9	10.7	11.6	12.6	13.8
10	5.7	6.3	7.0	7.6	8.3	8.9	9.7	10.5	11.3	12.3	13.5
13	5.5	6.1	6.7	7.3	8.0	8.6	9.4	10.1	11.0	11.9	13.1
15	5.4	6.0	6.6	7.2	7.8	8.5	9.2	9.9	10.7	11.7	12.8
18	5.2	5.8	6.4	7.0	7.6	8.2	8.9	9.6	10.4	11.3	12.4
22	5.0	5.6	6.1	6.7	7.3	7.9	8.5	9.3	10.0	10.9	12.0
26	4.8	5.4	5.9	6.5	7.0	7.6	8.2	8.9	9.7	10.5	11.6
28	4.8	5.3	5.8	6.3	6.9	7.5	8.1	8.8	9.5	10.4	11.4

Temp	Relative Humidity (%)						**BARLEY** (Modified Chung-Pfost)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	10.9	11.6	12.3	13.0	13.8	14.6	15.4	16.3	17.3	18.5	19.9
5	10.7	11.4	12.1	12.8	13.6	14.4	15.2	16.1	17.1	18.3	19.7
8	10.5	11.2	11.9	12.6	13.4	14.2	15.0	15.9	16.9	18.1	19.5
10	10.3	11.1	11.8	12.5	13.3	14.1	14.9	15.8	16.8	18.0	19.4
13	10.1	10.9	11.6	12.3	13.1	13.9	14.7	15.6	16.7	17.8	19.2
15	10.0	10.7	11.5	12.2	13.0	13.8	14.6	15.5	16.5	17.7	19.1
18	9.8	10.6	11.3	12.0	12.8	13.6	14.4	15.4	16.4	17.6	19.0
22	9.6	10.3	11.1	11.8	12.6	13.4	14.2	15.2	16.2	17.4	18.8
26	9.3	10.1	10.8	11.6	12.4	13.2	14.0	15.0	16.0	17.2	18.6
28	9.2	10.0	10.7	11.5	12.3	13.1	13.9	14.9	15.9	17.1	18.5

Temp	Relative Humidity (%)						**OATS** (Modified Oswin)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.8	10.3	10.9	11.4	11.9	12.5	13.1	13.7	14.5	15.3	16.4
5	9.6	10.1	10.6	11.1	11.7	12.2	12.8	13.5	14.2	15.1	16.2
8	9.3	9.8	10.3	10.9	11.4	12.0	12.6	13.3	14.0	14.9	15.9
10	9.1	9.7	10.2	10.7	11.3	11.8	12.4	13.1	13.9	14.7	15.8
13	8.9	9.4	10.0	10.5	11.0	11.6	12.2	12.9	13.7	14.5	15.6
15	8.8	9.3	9.8	10.3	10.9	11.5	12.1	12.8	13.5	14.4	15.5
18	8.5	9.1	9.6	10.1	10.7	11.3	11.9	12.6	13.3	14.2	15.3
22	8.3	8.8	9.3	9.9	10.4	11.0	11.6	12.3	13.1	14.0	15.1
26	8.0	8.6	9.1	9.6	10.2	10.8	11.4	12.1	12.9	13.8	14.8
28	7.9	8.4	9.0	9.5	10.1	10.7	11.3	12.0	12.8	13.7	14.7

Temp	Relative Humidity (%)						**PEAS** (Modified Henderson)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.2	10.2	11.3	12.4	13.5	14.7	15.9	17.3	18.8	20.4	22.4
5	9.0	10.1	11.1	12.2	13.3	14.5	15.7	17.1	18.5	20.2	22.2
8	8.9	9.9	11.0	12.1	13.2	14.3	15.6	16.9	18.3	20.0	21.9
10	8.8	9.9	10.9	12.0	13.1	14.2	15.4	16.8	18.2	19.8	21.8
13	8.7	9.7	10.8	11.8	12.9	14.1	15.3	16.6	18.0	19.6	21.5
15	8.7	9.7	10.7	11.7	12.8	13.9	15.1	16.4	17.9	19.5	21.4
18	8.6	9.6	10.6	11.6	12.7	13.8	15.0	16.3	17.7	19.3	21.2
22	8.4	9.4	10.4	11.4	12.5	13.6	14.8	16.0	17.4	19.0	20.9
26	8.3	9.3	10.2	11.3	12.3	13.4	14.5	15.8	17.2	18.7	20.6
28	8.2	9.2	10.2	11.2	12.2	13.3	14.4	15.7	17.1	18.6	20.5

Temp	Relative Humidity (%)						**LENTILS** (Modified Oswin)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	9.1	10.0	11.0	12.0	13.1	14.3	15.7	17.3	19.1	21.5	24.5
5	9.0	9.9	10.8	11.8	12.9	14.1	15.4	17.0	18.8	21.1	24.2
8	8.8	9.7	10.6	11.6	12.7	13.9	15.2	16.7	18.5	20.8	23.8
10	8.7	9.6	10.5	11.5	12.5	13.7	15.0	16.5	18.3	20.6	23.6
13	8.5	9.4	10.3	11.3	12.3	13.5	14.8	16.3	18.0	20.3	23.2
15	8.4	9.3	10.2	11.1	12.2	13.3	14.6	16.1	17.8	20.1	23.0
18	8.3	9.1	10.0	10.9	12.0	13.1	14.3	15.8	17.5	19.7	22.6
22	8.1	8.9	9.7	10.7	11.7	12.8	14.0	15.4	17.1	19.3	22.1
26	7.8	8.6	9.5	10.4	11.4	12.4	13.6	15.0	16.7	18.8	21.6
28	7.7	8.5	9.4	10.3	11.2	12.3	13.5	14.9	16.5	18.6	21.4

Temp	Relative Humidity (%)						**RED LENTILS** (Modified Halsey)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	8.8	9.3	9.8	10.4	11.0	11.8	12.6	13.5	14.7	16.2	18.3
5	8.7	9.2	9.7	10.3	10.9	11.6	12.4	13.4	14.5	16.0	18.0
8	8.5	9.0	9.6	10.1	10.7	11.4	12.2	13.2	14.3	15.8	17.8
10	8.5	8.9	9.5	10.0	10.6	11.3	12.1	13.1	14.2	15.7	17.7
13	8.3	8.8	9.3	9.9	10.5	11.2	12.0	12.9	14.0	15.5	17.4
15	8.3	8.7	9.3	9.8	10.4	11.1	11.9	12.8	13.9	15.3	17.3
18	8.2	8.6	9.1	9.7	10.3	10.9	11.7	12.6	13.7	15.1	17.1
22	8.0	8.5	9.0	9.5	10.1	10.7	11.5	12.4	13.5	14.9	16.8
26	7.9	8.3	8.8	9.3	9.9	10.6	11.3	12.2	13.3	14.6	16.5
28	7.8	8.2	8.7	9.2	9.8	10.5	11.2	12.1	13.1	14.5	16.4

Temp	Relative Humidity (%)						**SOYBEANS** (Modified Halsey)				
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	6.9	7.5	8.2	8.9	9.8	10.8	12.0	13.5	15.3	17.7	21.1
5	6.8	7.4	8.1	8.9	9.7	10.7	11.9	13.3	15.1	17.5	20.9
8	6.7	7.3	8.0	8.8	9.6	10.6	11.8	13.2	15.0	17.4	20.8
10	6.7	7.3	8.0	8.7	9.6	10.5	11.7	13.1	14.9	17.3	20.6
13	6.6	7.2	7.9	8.6	9.5	10.4	11.6	13.0	14.8	17.1	20.5
15	6.6	7.2	7.8	8.6	9.4	10.4	11.5	12.9	14.7	17.0	20.3
18	6.5	7.1	7.7	8.5	9.3	10.3	11.4	12.8	14.5	16.9	20.2
22	6.4	7.0	7.6	8.4	9.2	10.1	11.2	12.6	14.3	16.6	19.9
26	6.3	6.9	7.5	8.2	9.0	10.0	11.1	12.5	14.2	16.4	19.7
28	6.3	6.8	7.5	8.2	9.0	9.9	11.0	12.4	14.1	16.3	19.6

Temp	Relative Humidity (%)					**FLAX** (Modified Henderson/Chung-Pfost)					
(°C)	35	40	45	50	55	60	65	70	75	80	85
2	7.1	7.6	8.1	8.6	9.1	9.7	10.2	10.8	11.5	12.3	13.2
5	6.9	7.4	7.9	8.4	8.9	9.4	10.0	10.6	11.2	12.0	12.9
8	6.7	7.2	7.7	8.2	8.7	9.2	9.7	10.3	11.0	11.8	12.7
10	6.6	7.1	7.5	8.0	8.5	9.0	9.6	10.2	10.8	11.6	12.5
13	6.4	6.9	7.3	7.8	8.3	8.8	9.4	10.0	10.6	11.4	12.3
15	6.3	6.7	7.2	7.7	8.2	8.7	9.3	9.8	10.5	11.2	12.1
18	6.1	6.6	7.0	7.5	8.0	8.5	9.1	9.6	10.3	11.0	11.9
22	5.9	6.4	6.8	7.3	7.8	8.3	8.8	9.4	10.0	10.8	11.7
26	5.7	6.2	6.6	7.1	7.6	8.1	8.6	9.2	9.8	10.5	11.4
28	5.6	6.1	6.5	7.0	7.5	8.0	8.5	9.1	9.7	10.4	11.3

Using Supplemental Heat with Natural Air Drying

Rain, snow, and cool temperatures at harvest time mean producers must manage grain in the bin as carefully as they manage it in the field. Adding supplemental heat to natural air drying (NAD) can be an efficient and effective way to dry grain in bins if done correctly. It is also a way to extend the drying season.

Adding Heat Affects the Capacity of Air to Dry Grain

For every 10 C increase in the temperature of the air going into the bin, the relative humidity (RH) of the air is cut in half. With added heat, a cold, drizzly fall day can be turned into a beautiful drying day.

Example: Target moisture content of wheat for safe storage is 14.4 per cent. When ambient air conditions are 5 C and 70 per cent RH, the EMC for wheat (chart below) is 16.1 per cent; as such, the air does not have the capacity to dry under those conditions. However, by increasing the air temperature to 15 C using some heat, the resulting RH will be cut in half, to about 35 per cent, and the air will have capacity to dry since its EMC for wheat will now be 10.3 per cent.

Supplemental heating is not the same as heated air drying.

Heat/temperature draws moisture out of the kernel. Airflow rate moves moisture out of the grain.

The key is to match the moisture removal rate from the kernel with the removal rate from the bin.

Determining Heater Size and Type Required

The size of heater you need depends on two things:

1. The air flow rate (cfm) from your fan, and
2. Your desired temperature increases.

Heater capacity = temp. increase x air flow rate x 2.05
(btu/hr = C x cfm x 2.05)

Temp	Relative Humidity (%)								
°C	35	40	45	50	55	60	65	70	75
-2	11.5	12.2	13.0	13.7	14.5	15.3	16.0	16.9	17.7
2	11.1	11.9	12.6	13.4	14.1	14.9	15.6	16.4	17.3
5	10.9	11.7	12.4	13.1	13.8	14.6	15.3	16.1	17.0
8	10.7	11.5	12.2	12.9	13.6	14.3	15.1	15.8	16.7
10	10.6	11.3	12.0	12.7	13.4	14.2	14.9	15.7	16.5
13	10.4	11.1	11.8	12.5	13.2	13.9	14.6	15.4	16.2
15	10.3	11.0	11.7	12.4	13.1	13.8	14.5	15.2	16.1
18	10.1	10.8	11.5	12.2	12.9	13.6	14.3	15.0	15.8
22	9.9	10.6	11.3	11.9	12.6	13.3	14.0	14.7	15.5

Example1: To raise the air temperature by 10 C for a bin/fan that is pushing 5000 cfm, the required heater capacity is 10 x 5000 x 2.05 = 102,500 btu/hr.

Example 2: If you have a 100,000 btu/hr heater and you attach it to a bin/fan that is pushing 7500 cfm, the expected temperature increase will be 100,000/7500/2.05 = 6.5 C.

Keep in mind these equations assume a highly efficient heat transfer setup meaning all of the heat generated by the heater ends up in the air. The overall efficiency of some systems may be as low as 50 per cent, so estimate the required size of your heater accordingly.

Indirect or Direct-fired Heating Systems

Combustion of fuels like propane or natural gas does generate water, but the amount of water added to air is negligible compared to the amount of water being removed from the bin. For example, the amount of water added to the air using a propane heater (assuming 10 C increase for 5,000 cfm) is approximately 10 lb/hr. The amount of water being removed from the bin is approximately 120-200 lb/hr depending on the rate of drying.

Fuel Type

The total fuel cost theoretically depends on its cost ($/L) AND its energy density. The cost will fluctuate from month to month and region to region, but the energy density is constant. Propane and natural gas are considered "clean burning" fuels, so they can be used to directly heat the air entering the fan or bin. Diesel should only be used as an indirect source of heat.

Fuel	Fuel Cost* (variable)		Energy Density (fixed)		Fuel Cost (variable)		Fuel Cost (variable)
Diesel	$1.63/L	DIVIDED BY	38.6 MJ/L	EQUALS	$0.042/MJ	X 1056	$44.59 per million btu
Natural Gas*	$0.215/m3		37.0 MJ/m3		$0.0058/MJ		$6.14 per million btu
Propane	$0.73/L		25.3 MJ/L		$0.029/MJ		$30.47 per million btu

** SK rates as of January 2025*

General Management Practices for NAD Systems with Supplemental Heat

1. Only use a CSA certified heater that is designed for use with grain storage fans for safety and grain quality reasons. Follow manufacturer's instructions for installation and operation.

2. Ensure adequate air flow rate (minimum 1 cfm/bu) or there is a risk of overheating the grain.

   Low air flow rates may not have enough energy to fully remove moisture from the bin.

3. Aim for a plenum temperature of 15-25 C, but limit air temperature increase to 15 C or less.

   Higher temperature increases result in high fuel costs, reduced heat transfer efficiency, increased chance of over drying, and increased chance of condensing and freezing at edge of bin.

4. Do not exceed a plenum (after heater) temperature of 30 C.

   Even though higher temp = more drying capacity, you do not want to overheat the grain.

   Air flow rates of 0.75 to 1 cfm/bu can "keep up" with moderate drying rates, but not with high drying rates associated with high temperatures (>30 C).

5. As much as possible, maintain a CONSISTENT air temperature going into the bin.

   Thermostatic controllers are becoming more common and will help achieve a consistent temperature going into the bin. This will help minimize day-to-night variations in temperature.

6. Ensure adequate ventilation in the headspace since condensation on a cold bin roof can cause moisture problems in the stored grain.

   A minimum of one square foot of vent space for every 1000 cfm of air flow is required.

   Consider the use of "active" ventilation in the headspace to expel moist air more effectively.

7. Consider turning the bottom grain once the average bin moisture is dry to distribute over-dry grain.

8. Grain MUST BE cooled to less than 15 C after drying

   Cooling will also remove some moisture, so drying may be complete when moisture is within 0.5 per cent of target.

9. Monitor grain conditions with in-bin cables and/or samples during drying.

More information on PAMI research projects is available on their website, https://pami.ca/.

List of Additional Resources

Scan the QR Codes below to download Ministry of Agriculture publications and resources.

Guide to Crop Protection	Crop Planning Guide	Soil Fertility and Crop Rotation Planning Guide	Webinars for Farmers and Ranchers

Additional Agronomic Tools and Publications

Canola Encyclopedia: www.canolacouncil.org/canola-encyclopedia/

Cutworm Pests of Crops on the Canadian Prairies: https://prairiepest.ca/wp-content/uploads/2019/05/Cutworm-booklet-Final-EN-May1-2017.pdf

Digging into Canadian Soils An Introduction to Soil Science: https://openpress.usask.ca/soilscience/

Diseases of Field Crops in Canada: http://phytopath.ca/publications/5479-2/

Durum Production Manual: https://saskwheat.ca/durum-production-manual

Feekes Growth Scale: www.soilcropandmore.info/crops/Wheat/production/whtmang.htm

Field Scouting Guide-Manitoba Agriculture: https://www.gov.mb.ca/agriculture/crops/guides-and-publications/#fsg

Growing Flax-Flax Council of Canada: www.flaxcouncil.ca/growing-flax/introduction

Insect Pest of the Prairies: Available through numerous book sellers

Manage Resistance Now: www.manageresistancenow.ca

Mustard Production Manual: https://saskmustard.com/production-manual/index.html

Prairie Pest Monitoring Network Blog: http://prairiepestmonitoring.blogspot.com/

Pulse Crop Production-Sask Pulse Growers: https://saskpulse.com/growing-pulses/

Saskatchewan Sunflower Committee: http://sksunflowers.com/

Soil Orders in Saskatchewan: soilsofsask.ca

Sprayer Application Technology: http://sprayers101.com/

Weeds of the Prairies-Alberta Agriculture and Rural Development: alberta.ca/agriculture-and-irrigation.aspx

Weeds of the West: Available through numerous book sellers

Winter Cereal Survival Model Research Tool: https://norstar.usask.ca/survivalmodel/

Wireworm Guide-Agriculture and Agri-Food Canada: https://publications.gc.ca/collections/collection_2021/aac-aafc/A42-125-2021-eng.pdf

Zadoks Scale for Crop Staging: www.fao.org/docrep/006/x8234e/x8234e05.htm

Conversion Tables

Table 1: Metric Conversion Factors (Approximate)*

Metric Unit	Metric to Imperial	Imperial Unit	Imperial to Metric	Metric Unit
Linear centimetre (cm)	 x 0.39	Linear inch	 x 2.54	Linear centimetre (cm)
Area square metre (m^2) hectare (ha)	 x 1.2 x 2.5	Area square yard acres	 x 0.84 x 0.4	Area square metre (m^2) hectare (ha)
Volume litre (L)	 x 0.22	Volume gallon	 x 4.55	Volume litre (L)
Pressure kilopascals (kPa)	 x 0.14	Pressure psi	 x 6.9	Pressure kilopascals (kPa)
Weight gram(g) kilogram (kg)	 x 0.04 x 2.2	Weight ounce (oz) pound (lb)	 x 28.35 x 0.454	Weight gram(g) kilogram (kg)
Agricultural litres per hectare (L/ha) litres per hectare (L/ha) litres per hectare (L/ha) mililitres per hectare (mL/ha) kilograms per hectare (kg/ha) grams per hectare (g/ha)	 x 0.089 x 0.357 x 0.71 x 0.014 x 0.89 x 0.014	Agricultural gallons/acre quarts/acre pints/acre fluid ounces (fl. oz)/acre pounds (lb)/acre ounces (oz)/acre	 x 11.23 x 2.81 x 1.41 x 70.22 x 1.12 x 70	Agricultural litres per hectare (L/ha) litres per hectare (L/ha) litres per hectare (L/ha) mililitres per hectare (mL/ha) kilograms per hectare (kg/ha) grams per hectare (g/ha)

*Example-To convert centimetres to inches, multiply by 0.39; conversely, to convert inches to centimetres, multiply by 2.54. Caution-Herbicide labels are in metric units only. Conversion between the Metric and Imperial system may result in confusion. It is recommended to use metric units only.

Table 2: Imperial gallon conversion and V/V cheat sheet

Imperial gallons	Litres (L)	0.25% V/V (in Litres)	0.5% V/V (in Litres)
500	2273	5.7	11.4
800	3637	9.1	18.2
1000	4546	11.4	22.7
1200	5455	13.6	27.3
1600	6056	15.1	30.3

Table 3: US gallon conversion and V/V cheat sheet

US gallons	Litres (L)	0.25% V/V (in Litres)	0.5% V/V (in Litres)
500	1892	4.7	9.5
800	3028	7.6	15.1
1000	3785	9.5	18.9
1200	4542	11.4	22.7
1600	6057	15.1	30.3

Table 6: Crop Bushel Weights and Bushel Equivalents Per Tonne

Crop	lbs/Bushel	Bushels/tonne
Wheat	60	36.744
Oats	34	64.842
Barley	48	45.930
Rye	56	39.368
Flaxseed	56	39.368
Canola/Rapeseed	50	44.092
Corn	56	39.368
Soybeans	60	36.744
Peas	60	36.744
Lentils	60	36.744
Chick Peas	60	36.744
Sorghum	56	39.368
Buckwheat	48	45.930
Mustard	50	44.092
Sunflower	30	73.478
Canary Seed	50	44.092
Faba Beans	60	36.744
Triticale	52	42.396

Courtesy of Canadian Grain Commission

Pest Surveys

To understand the risks and potential damage associated with these pests, the Ministry of Agriculture and its partners monitor the presence, abundance and impact of important crop pests in Saskatchewan. We use this information to build forecast maps, make recommendations for control and for research purposes. This information is freely available and can be used by growers to make informed seed purchase and pest management decisions. The Ministry of Agriculture is adopting a permission-based survey system. This means that we need the help of growers by granting us permission to access land to complete this important work. Find out more on pest surveys and how to sign up by scanning the QR code or by visiting saskatchewan.ca/agriculture.

Crop Protection Lab

The Crop Protection Lab provides diagnostic services to help growers identify and deal with pests that affect production. We offer diagnostic services in the areas of: plant health, insects, weed control and herbicide resistance screening. The lab is open year-round to diagnose problems and recommend solutions using up-to-date technology and expertise. The accuracy of our laboratory's diagnosis of your sample is dependent on the quality of the sample submitted and the inclusion of relevant information. Below are some tips on how to collect, package and submit specimens:

- Never add water to the samples or the packaging as this will result in rotting or saprophytic growth. (The only exception is for disease samples where viral causal agents are suspected. For specimens of this nature the sample needs to be maintained in as fresh a state as possible. For above-ground parts showing symptoms, wrap individual parts between lightly moistened paper towels and ship to the lab as quickly as possible.)
- If possible avoid sending in fresh specimens over the weekend to prevent decay in shipping.
- A sample cannot be too large but it can be too small. See forms for sample size information. The information about the sample may be as significant as the sample itself so provide as much information as possible.
- Remember to complete and include the correct sample form available on this website. Samples cannot be tested without a completed form. Both form and sample should be submitted together.

Find out more about the Crop Protection Lab by scanning the QR code or by visiting saskatchewan.ca/agriculture.

Sign Up to Be a Crop Reporter

The Crop Report is created weekly using local data to give an accurate representation of the current on-farm conditions throughout Saskatchewan. Information from the report is used across Saskatchewan and world-wide by producers, agrologists, policymakers, media, marketers, investors and others interested or involved with the agricultural industry.

Are you a weather-watcher who checks the rain gauge each morning? Do you enjoy discussing farming and crop conditions with your neighbours? Then consider becoming a volunteer Crop Reporter with the Ministry of Agriculture.

Find out more about becoming a Crop Reporter by scanning the QR code or by visiting saskatchewan.ca/agriculture.

For More Information

Contact your nearest Saskatchewan Agriculture regional office:

Kindersley
306-463-5513

Outlook
306-867-5527

Swift Current
306-778-8285

Humboldt
306-682-6701

Moose Jaw
1-866-457-2377

Prince Albert
306-953-2363

Tisdale
306-878-8842

Weyburn
306-848-2857

North Battleford
306-446-7962

Yorkton
306-786-1531

Agriculture Knowledge Centre (Toll Free): 1-866-457-2377

Farm Stress Line: 1-800-667-4442