13. Weed Control

Crop Yield Losses Due to Weeds

Yield losses due to weed competition will be greatest when:

- weeds are allowed to emerge with or prior to crop emergence
- weeds are at high densities
- there is limited soil moisture

Weed control is an important part of crop production. Ineffective weed management can easily cause yield losses in excess of 80%. In general, agronomic practices that produce a healthy, fast-growing crop will provide the best competition against weeds. When developing a weed control program, consider cultivation, rotation and other effective cultural practices for weed control, along with herbicide treatments. Any single method of weed control, or the continuous use of the same herbicide program, will lead to the build-up of weeds resistant or tolerant to that control method.

An integrated approach to weed management that uses all available weed control strategies to manage weed populations creates a cropping system that is more resilient to herbicide failures, since it does not exclusively rely on the use of herbicides to control weeds.

Integrated Weed Management Strategies

Integrated weed management strategies include:

- **Field scouting** to determine the weed species present, when they emerge, the relative density of each species and how they reproduce (e.g., by seed, underground roots). Knowing this information will help construct a management plan that will attack each species when they are most vulnerable. Additional scouting is required following the implementation of control measures to evaluate its effectiveness. There is no excuse to not scout, especially when there are many easy and accurate ways to record field information. A photo taken by a smartphone will document the date and location of the weed species in the photo, and is all that is needed to track weed emergence and effectiveness of the management plan.

- **Crop rotations** are effective in reducing weeds. Historically in Ontario, weed control failures due to herbicide-resistant weed populations have shown up in farming operations that lacked a diverse cropping rotation. When more crops are included in a rotation, there are different planting dates and seeding rates that cause canopy closure to occur at different times in the season. There are often different tillage systems, fertility programs and herbicides used in diverse crop rotations. These differences provide an unpredictable environment for any one weed population to thrive. When weed densities of different crop rotations have been evaluated, monocultures often contained higher weed densities compared to multi-crop rotations[1].

- **Cover crops** can suppress weed growth and reduce the amount of weed seeds returned to the soil. Typically, cover crops that are planted after cereal harvest provide the most benefit in reducing the amount of weed seeds produced and returned to the soil. A comparison of cover crops and their ability suppress weed growth can be found in Table 13–1, *Relative ranking of cover crops and their ability to suppress weeds.*

Table 13–1. Relative ranking of cover crops and their ability to suppress weeds

Adapted from the Midwest Cover Crops Council Cover Crop Decision Tool (http://mccc.msu.edu/).

Cover Crop	Ability to Suppress Weeds
Rye, winter cereal	excellent
Triticale, winter	excellent
Buckwheat[1]	excellent
Mustard, oriental[1]	excellent
Radish, oilseed[1]	excellent
Barley (spring or winter)	very good
Oats	very good
Triticale, spring	very good
Red clover	very good
Ryegrass, annual	good
Peas, field	good

[1] Do not allow these cover crops to go to seed, otherwise they will produce weedy volunteers for next season.

A study by the University of Guelph[2] demonstrated that when cover crops were incorporated into a sweet corn cropping system, profit margins were generally higher than when no cover crop was included even with higher costs associated with cover crop establishment. Furthermore, weed populations were lowered or no different than when no cover crop was included. Refer to Table 13–2, *Weed density in the spring following different summer-seeded cover crops*[2]. Most cover crops should not be allowed to go to seed, otherwise they will germinate next spring as volunteers and compete with the crop just like a weed.

Table 13–2. Weed density in the spring following different summer-seeded cover crops

Dominant weed species at Bothwell were common chickweed, Canada fleabane and henbit.

Dominant species at Ridgetown were common ragweed, volunteer oilseed radish and woodsorrel.

A difference of less than 1 plant/m² is statistically insignificant at the Bothwell site. At the Ridgetown site there is no statistical difference between oats, oilseed radish and no cover crop.

LEGEND: – = no data available

Cover Crop	Weed Density	
	Bothwell	**Ridgetown**
No cover crop	10.4 plants/m²	87.3 plants/m²
Oats	1.9 plants/m²	70.0 plants/m²
Oilseed radish	–	80.9* plants/m²
Oilseed radish + rye	0.4 plants/m²	155.8* plants/m²
Rye	0.5 plants/m²	64.8 plants/m²

Source: Adapted from O'Reilly, et al. 2011.

* Volunteer oilseed radish was a dominant species found at this location and was considered a weed for the purposes of data collection.

- **Fertilizers** (especially nitrogen) tend to stimulate the germination of some plant species and can affect the competition between crops and weeds in current and subsequent crops. Use of banded phosphorus and potassium tends to concentrate the nutrients most where the crop has access to them. Side-dress nitrogen applications disturb the soil, which may stimulate the germination of weeds but also places nitrogen in a narrow band below the depth from which most weeds germinate and grow. A four-year study in western Canada demonstrated significant reductions in the weed seed bank when nitrogen fertilizer was banded or injected versus broadcast applications[3].

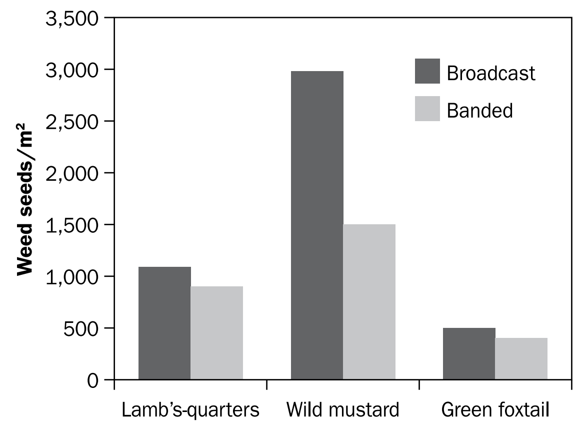

Figure 13–1. Effect of nitrogen fertilizer application method in four consecutive years on the weed seed bank at the conclusion of the four-year experiment.

- **Population and row width** can affect weed growth by closing the crop canopy sooner. Narrow rows, high populations and fast-growing cultivars can have a competitive edge over weeds. For example, a reduction in late-season weed escapes in corn has been observed in University of Guelph weed management trials when the crop is established at higher plant populations (104,000 plants/ha or 42,000 plants/acre), see Photo 13–1, compared to normal plant populations (84,000 plants/ha or 34,000 plants/acre), as seen in Photo 13–2. A number of seed corn companies offer seeding rate calculators to determine the most profitable seeding rate for a hybrid. If a hybrid responds positively to increased seeding rates, there is an opportunity to reduce the presence of later germinating weed species through quicker canopy closure. In cropping systems that use herbicides, the use of vigorous, high-quality seed to achieve uniform stands at the recommended plant populations, combined with early planting; gives the crop a head-start to compete with weeds. In organic cropping systems, or when growing a field crop where few herbicide options exist, delayed planting provides an opportunity to remove several flushes of weed emergence before planting, provides warmer soil conditions for quick crop emergence and generally puts the crop at a competitive advantage. Deep planting of crop seed can delay emergence and favour weed development, but alternatively can be effective if a shallow tillage is used prior to crop emergence to remove the initial flush of emerging shallow-rooted annual weeds.

Photo 13–1. Noticeably less weed pressure in a 42,000 ppa corn canopy shown in early September. The herbicide Liberty was applied at the 3–4 leaf stage of corn.

Photo 13–2. Weed pressure in a 34,000 ppa corn canopy shown in early September. The herbicide Liberty was applied at the 3–4 leaf stage of corn.

- **Tillage practices and mechanical weed control**
  - **No-till** — 75% of the weed seed bank is in the upper 5 cm (2 in.) of soil. The use of burndown herbicides has been effective for controlling many perennial weeds such as quackgrass.
  - **Mouldboard plow** — the seed bank is more uniformly distributed over the depth of the plow layer.
  - **Blind harrowing** — kills small weed seedlings just before crop emergence.
  - **Rotary hoe** — at 10–20 km/h, it has "fingers" that lift and mix soil, uprooting small weeds just before or shortly after crop emergence.
  - **Inter-row cultivation, or scuffling, of row crops** — uproots small weeds and cuts off larger ones and smothers weeds in the crop row. Relative size of crops to weeds and timing of cultivation will determine success.
  - **Mowing** — can help reduce weed biomass and seed production in crops such as newly established forages, cereal crops or cereal stubble.
- **Harvest weed seed management** — producers in Australia are using different techniques to remove weed seeds at harvest. This has been done out of necessity due to herbicide resistant weed issues but would equally be of value for herbicide failures due to environmental conditions. The most promising tool is called the Harrington Seed Destructor, invented by producer Ray Harrington. The destructor is a cage mill that processes chaff during harvest and has been shown to destroy 95% of weed seeds that pass through the combine at harvest. A unit is being tested in Canada to identify its efficacy on North American weed species.
- **Post-harvest weed management** — weed seed counts taken at 6 weeks after winter wheat harvest in Ontario revealed the potential to disperse over 50 million weed seeds. This illustrates the importance of post-harvest weed management to reduce the production of weed seeds. Some winter annual weeds, such as chickweed (Photo 13–3), henbit (Photo 13–4) and purple deadnettle (Photo 13–5) are alternative hosts for other crop pests and should be removed. Specifically, chickweed is an alternate host for wireworm, while henbit and purple deadnettle are alternate hosts for soybean cyst nematode. A study conducted in Indiana found that when henbit and purple deadnettle were allowed to grow in the fall, soybean cyst nematode population densities were higher[4].

Photo 13–3. Chickweed is an alternate host for wireworm.

Photo 13–4. Henbit is an alternate host for soybean cyst nematode.

Photo 13–5. Purple deadnettle is an alternate host for soybean cyst namatode.

- **Perennial weed management** — Shorter day lengths and cooler temperatures in late summer and early fall will trigger many perennial weeds to begin allocating carbohydrates to the roots for over-wintering, which allows for translocation of systemic herbicide down to the roots, resulting in density reductions the next spring. The use of glyphosate as either a pre- or post-harvest treatment targeting perennial weeds at the early bud to early flower stage has been one of the more effective strategies for reducing perennial weed populations. It is important to follow application timing information on the glyphosate's product label. In organic cropping systems, the use of tillage to pull root fragments to the surface and the use of cover crops to smother vegetative growth can also be helpful in reducing the persistence of perennial weeds.
- **Equipment practices** — equipment can carry weed seeds from field to field. Combines, tillage equipment, wind and soil erosion, animals and birds can all transport weeds. Application of manure or other soil amendments can also lead to weed infestations. Proper sanitation and cleaning of equipment, along with maintenance of field border areas, all benefit long-term weed management in the field.

Crop Competitiveness Against Weeds

Corn, soybeans, dry edible beans and flax are not strong competitors against weeds, so effective weed management during the critical period is needed to minimize yield losses. Canola, sunflowers, spring and winter cereals are stronger competitors against weeds, as is shown in Figure 13–2, *Typical yield losses of different field crops due to weed competition*. However, weed removal during the early part of crop development will minimize yield losses.

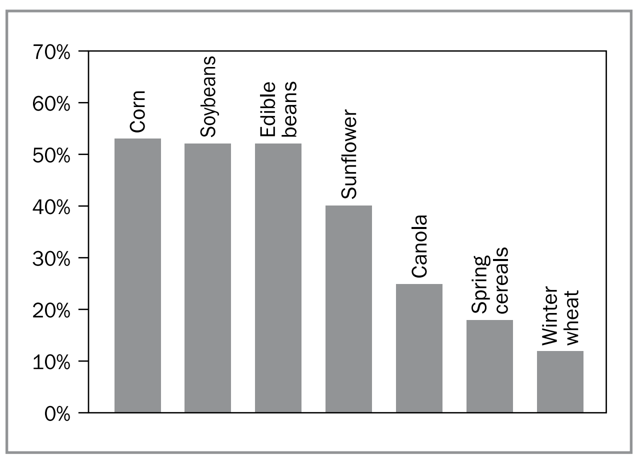

Figure 13–2. Typical yield losses of different field crops due to weed competition.

Adapted from several sources[5] (bibliography)

Critical Period for Weed Control in Field Crops

Yield loss caused by weeds is minimized when weeds are controlled during the critical period. Later-germinating weeds have a minimal impact on yields, but will still produce weed seeds that are returned to the soil.

The product label for post-emergent herbicides will identify the growth stage of weeds that is required for optimum control. Timing of post-emergent herbicides should ideally occur within the critical period for the crop and at the ideal growth stage of the weed. However, applying the herbicide at the correct weed stage is the greater priority, since if a species gets beyond that stage it increases the chance of poor control.

The critical periods highlighted in Table 13–3, *Critical weed-free periods for common Ontario field crops,* are guidelines. The point at which to execute weed control within the period will vary yearly and by site due to variations in climate, soil type, weed species and density. For example, the critical period will be earlier in the window for fields with light-textured soils under moisture stress conditions when weed densities are very high. Delaying control measures to the later part of the critical period in this situation would likely result in significant yield losses.

Table 13–3. Critical weed-free periods for common Ontario field crops

Crop	Critical Weed-Free Period	Source
Corn	3–10 corn leaf tips	Swanton (University of Guelph)
Soybean	first–third trifoliate-leaf stage (V2–V3)	Swanton (University of Guelph)
Spring cereals	1–3-leaf stage (Zadok's 10–13)	Van Dam, Swanton (University of Guelph)
Winter wheat	500–1,000 Growing Degree Days (Base Temp. = 0)	Welsh, et al., 1999 (University of Reading)
Forages	year of establishment: 4–6 weeks after planting	Dillehay (Penn State University)
Canola	emergence to 6-leaf stage	Van Acker (University of Guelph)

Impact of Soil Moisture on Weed Competitiveness

When soil moisture is abundant, the impact of weeds on crop yield loss is reduced. Table 13–4, *Corn and soybean yield losses from weeds under adequate soil moisture vs. inadequate soil moisture*, compares observed yield losses due to weeds in corn and soybeans at the Elora Research Station, in a season with more than adequate moisture compared to a "dry" season.

Table 13–4. Corn and soybean yield losses from weeds under adequate soil moisture vs. inadequate soil moisture

Precipitation May to August	Corn Yield Losses from Weeds	Soybean Yield Losses from Weeds
458 mm	18%	23%
218 mm	96%	84%

Source: Weed Science Research Program, Department of Plant Agriculture, University of Guelph (1986–2015).

Impact of Weed Species on Crop Yield Losses

Crop scouting determines the weed species present and their respective densities in the field. Certified crop advisors were asked to rank weed species they most commonly find in soybean, winter wheat and corn when scouting. See Table 13–5, *Top 30 most frequently found weeds in soybean, winter wheat and corn, according to a survey of Ontario Certified Crop Advisors (2014).* Some weeds are more competitive than others. Table 13–6, *Soybean and corn yield losses due to weeds at known populations,* shows the comparative yield losses caused by different weed species.

Consider weed competitiveness when deciding whether to treat escapes. The estimates in Table 13–6 are based on normal weather conditions with adequate soil moisture and weeds emerging with the crop. Yield losses may increase under drier soil conditions and may be variable under conditions of plant stress.

Also consider the effects of weed populations on crop quality and harvest procedures. For example, eastern black nightshade is not a big threat to yield but can have a severe effect on crop quality of identity-preserved (IP) soybeans.

Table 13–5. Top 30 most frequently found weeds in soybean, winter wheat and corn, according to a survey of Ontario Certified Crop Advisors (2014)

Rank in Soybean	Weed	Rank in Winter Wheat	Weed	Rank in Corn	Weed
1	lamb's-quarters	1	dandelion	1	lamb's-quarters
2	common ragweed	2	chickweed	2	pigweed, redroot
3	dandelion	3	lamb's-quarters	3	common ragweed
4	pigweed, redroot	4	common ragweed	4	green foxtail
5	Canada fleabane	5	Canada fleabane	5	dandelion
6	green foxtail	6	perennial sowthistle	6	yellow nutsedge
7	nightshade, eastern black	7	pigweed, redroot	7	yellow foxtail
8	yellow nutsedge	8	milkweed	8	barnyard grass
9	perennial sowthistle	9	field bindweed	9	velvetleaf
10	barnyard grass	10	tufted vetch	10	perennial sowthistle
11	annual sowthistle	11	shepherd's purse	11	annual sowthistle
12	velvetleaf	12	lady's thumb	12	field horsetail
13	yellow foxtail	13	wild carrot	13	nightshade, eastern black
14	field horsetail	14	speedwell species	14	Canada fleabane
15	giant ragweed	15	field horsetail	15	giant foxtail
16	milkweed	16	annual bluegrass	16	chickweed
17	field bindweed	17	annual sowthistle	17	crabgrass, large
18	lady's thumb	18	prickly lettuce	18	lady's thumb
19	tufted vetch	19	burdock	19	field bindweed
20	giant foxtail	20	yellow foxtail	20	crabgrass, smooth
21	crabgrass, smooth	21	giant ragweed	21	proso millet
22	annual bluegrass	22	curled dock	22	giant ragweed
23	chickweed	23	barnyard grass	23	pigweed, green
24	wild carrot	24	quackgrass	24	quackgrass
25	fall panicum	25	green foxtail	25	annual bluegrass
26	quackgrass	26	wild buckwheat	26	fall panicum
27	spreading atriplex	27	velvetleaf	27	spreading atriplex
28	crabgrass, large	28	wild mustard	28	cocklebur
29	proso millet	29	scentless chamomile	29	wild buckwheat
30	pigweed, green	30	dogbane	30	volunteer alfalfa

Mechanical Weed Control

Small annual weed seedlings can be partially controlled by blind harrowing prior to crop emergence. Use a set of light harrows, operating at a shallow depth. Once the crop has emerged, a weeder-harrow (with L-shaped flexible tines) can be used until the crop is 5–10 cm (2–4 in.) tall. Timing of harrowing operations is critical to achieve success, since the weeds must be small and the soil surface dry and easily worked. Cultivation with the rotary hoe at high speeds 10 km/h and at shallow, 2.5–3 cm (1–1.5 in.), depths when corn is 7–8 cm (3 in.) high or when beans are in the 1–2 leaf stage will help control small weed seedlings. These techniques will not reduce herbicide action and may in some years enhance chemical weed control. Under dry soil conditions, rotary hoeing dry edible beans 7–10 days following planting will help control emerging weeds but can also help activate soil-applied herbicides by mixing the chemical with moist soil. Rotary hoeing is unlikely to remove weeds that are past the two-true-leaf stage.

Use inter-row cultivation to complement other weed control measures; it is most effective when weeds are small. Cultivate to a shallow depth to reduce germination of new weed seeds, soil moisture loss and crop root injury. Inter-row cultivation may be required when weeds escape a herbicide treatment. Consider weeds as escapes when they are 5–7 cm (2–3 in.) high. Since cultivation is less successful on larger weeds, cultivate quickly after determining a herbicide failure. If weeds are too large, consider alternative herbicide choices.

Band treatment of chemical over the row will reduce herbicide cost by half to two-thirds, depending on the row spacing and the width of the band. Control weeds between the bands with shallow inter-row cultivation. Consider the combination of the two operations when evaluating the economics of treating weeds in this manner.

Herbicide Resistance

The University of Guelph has confirmed 19 herbicide-resistant weed species in Ontario. These resistant species affect the performance of eight different herbicide modes of action. See Table 13–7, *Weed populations confirmed resistant to herbicide groups in Ontario (January 2016).*

Herbicide-resistant weed species will dominate a field's weed population when herbicides from a single chemical mode of action are used repeatedly. The speed at which herbicide-resistant weed populations are selected will depend on the complexity of the crop rotation and the herbicide modes of action repeatedly used. Applying the principles of integrated weed management will delay the onset of herbicide-resistant weed populations. To prevent or slow the development of resistant weeds, use the following approaches:

- identify, monitor and keep records
- rotate crops and herbicide mode of action
- prevent spread of weeds
- use alternatives to chemical weed control

Herbicide Injury

When the directions on a herbicide product label are followed correctly, the risk of injury to the target crop is very small. However, under less-than-favourable conditions, all herbicides have the potential to cause crop injury. The primary sources of herbicide injury to crops are:

- herbicide residues persisting from the previous crop year, especially in areas where spray overlaps occurred
- excessive product rate due to a miscalculation or spray overlap

Table 13–6. Soybean and corn yield losses due to weeds at known populations

Crop losses assume that the weeds have emerged with the crop.

Crop	Weed	Yield Loss: 1 plant/m²	Yield Loss: 5 plants/m²
Corn	**Annual Broadleaves**		
	Giant ragweed	13%	36%
	Lamb's-quarters	12%	35%
	Pigweed	11%	34%
	Cocklebur	6%	22%
	Ragweed	5%	21%
	Wild mustard	5%	18%
	Velvetleaf	4%	15%
	Lady's thumb	3%	13%
	Wild buckwheat	2%	10%
	Eastern black nightshade	2%	7%
	Annual Grasses		
	Giant foxtail	2%	10%
	Proso millet	2%	10%
	Fall panicum	2%	10%
	Barnyard grass	2%	7%
	Green foxtail	2%	7%
	Yellow foxtail	1%	5%
	Old witch grass	1%	5%
	Crabgrass	1%	3%
Soybeans	**Annual Broadleaves**		
	Cocklebur	15%	41%
	Eastern black nightshade[1]	14%	40%
	Giant ragweed	14%	40%
	Lamb's-quarters	13%	38%
	Pigweed	12%	36%
	Ragweed	10%	33%
	Velvetleaf	6%	23%
	Wild mustard	5%	20%
	Lady's thumb	4%	15%
	Wild buckwheat	4%	15%
	Annual Grasses		
	Volunteer corn	4%	15%
	Giant foxtail	3%	12%
	Proso millet	3%	12%
	Barnyard grass	3%	12%
	Fall panicum	2%	10%
	Green foxtail	2%	8%
	Yellow foxtail	1%	5%
	Old witch grass	1%	4%
	Crabgrass	1%	4%

[1] Eastern black nightshade in soybeans reduces its quality.

Table 13–7. Weed populations confirmed resistant to herbicide groups in Ontario (January 2016)

Mode of Action	Resistant Weed Species
Lipid synthesis (ACCase) inhibitors (Group 1) (e.g., Assure II, Excel, Poast Ultra, Venture)	One species: large crabgrass
Amino acid synthesis inhibitors (Group 2) (e.g., Accent, Classic, Pinnacle, Pursuit, Ultim)	Eleven species: cocklebur, Canada fleabane[1], common ragweed[2], eastern black nightshade, foxtail (green and giant), giant ragweed[1], lamb's-quarters[2], pigweed (redroot and green)[2], waterhemp[2]
Growth regulators (Group 4 – benzoic acids) (e.g., Banvel II, Distinct)	One species: wild carrot
Systemic photosynthetic inhibiting herbicides triazines (Group 5) (e.g., Atrazine, Sencor, Princep Nine-T)	Ten species: barnyard grass, common groundsel, common ragweed[3], lamb's-quarters[3], pigweed (redroot and green)[3], waterhemp[3], wild mustard, witchgrass, yellow foxtail
Non-systemic photosynthetic inhibiting herbicides (Group 6) (e.g., Basagran, Pardner)	Two species: pigweed (redroot and smooth)
Systemic photosynthetic inhibiting herbicides substituted ureas (Group 7) (e.g., Lorox)	Two species: pigweed (redroot and green)
Aromatic amino acid synthesis inhibitors (Group 9) (e.g., glyphosate, Roundup, Weathermax, Touchdown Total)	Four species: Canada fleabane[3], common ragweed, giant ragweed[3], waterhemp[2,3]
Bipyridiliums (Group 22) (e.g., Reglone, Gramoxone)	Three species: Canada fleabane, eastern black nightshade, field peppergrass

[1] Populations exist that are also resistant to group 9 herbicides (e.g., glyphosate).
[2] Populations exist that are also resistant to group 5 herbicides (e.g., atrazine).
[3] Populations exist that are also resistant to group 2 herbicides (e.g., FirstRate, Pursuit).

- tank contamination due to fungicide or insecticide application that has herbicide residues in the spray solution when applied (e.g., a Folicur application on winter wheat that contains Ultim residues will cause considerable crop injury and yield loss)
- off-target drift from a herbicide application to a neighbouring crop
- herbicide applications made past the labelled crop stage (in cereals, late applications occurring close to heading time can interfere with pollination and reduce yield)
- adverse environmental conditions around the time of application or crop emergence
- air temperature fluctuations of more than 20°C or daytime highs exceeding 30°C will dramatically increase the potential for herbicide injury
- excessive rain after a soil-applied herbicide application can cause the herbicide to "splash up" onto the leaves, causing injury
- inappropriate rate applied to higher-risk soils
- impact of certain herbicides (e.g., metribuzin) when applied to soils that have a high pH and are low in organic matter, they are more available for plant uptake and the risk of crop injury is increased if the product rate is not reduced as per labelled instructions

Crop growth stage, variety, stress, environmental conditions, tank-mix partners and adjuvants will all affect the potential amount and severity of crop injury. When the target crop is under stress, its ability to metabolize a herbicide is reduced and injury may result. A herbicide's mode of action will also influence the severity of crop injury. In general, while contact herbicide injury may look worse, systemic herbicides will have longer-lasting injury, which may be more severe. Each herbicide's product label will have a precautionary section outlining circumstances that may increase the potential for crop injury. Review these sections to minimize the potential of herbicide injury, and refer to *Injury symptoms at various plant locations caused by different herbicide families.*

Injury Symptoms at Various Plant Locations Caused by Different Herbicide Families

This section describes the injury symptoms to plants typically caused by different herbicide families. The mode of action for each herbicide family will affect a different part of the plant. The information below is organized by the affected location on the plant and the type of injury that would be expected from each herbicide family.

Injury to Newly Emerged Seedling Plants

Dinitroanalines (Group 3)
(systemic – xylem mobile)
(e.g., Prowl H2O, Treflan)

- stunted plants that do not fully emerge from the soil
- short, thick lateral roots
- impact on yield will depend on severity of injury and crop stage at time of injury

Grassy Plants
- shoots are short, thick and may appear red or purple (Photo 13–6)
- thinning of plant stands (Photo 13–7)

Broadleaf Plants
- may have swollen and cracked hypocotyls (area below cotyledons)

Diphenylethers (Group 14)
(systemic – xylem mobile)
(e.g., Authority, Authority Supreme, Fierce, Valtera)

- thickening of roots, necrotic (brown) lesions on roots
- impact on yield will depend on severity of injury
- leaf distortion/crinkling, browning of leaf margins and damaged growing point (Photo 13–8)

Grassy Plants
- shoots are short and thick, leaf tissue distorted and plant establishment is reduced

Broadleaf Plants
- may have swollen and cracked hypocotyls (area below cotyledons)
- crinkled and distorted leaves with necrotic (brown) leaf margins (Photo 13–9)
- severe leaf distortion and burn can damage the growing point and reduce soybean populations (Photo 13–10)

Photo 13–6. Pendimethalin (Prowl) injury in corn causes short, thick and stunted roots.

Photo 13–7. Thinning of a corn stand caused by excessive trifluralin (e.g., Treflan) residues due to a sprayer overlap in the previous year's edible bean crop.

Photo 13–8. Severe necrosis and distortion of soybean leaf tissue from excessive plant uptake of flumioxazin (e.g., Valtera). In this photo heavy rainfall after application coincided with crop emergence.

Photo 13–9. Severe leaf distortion caused by flumioxazin (e.g., Valtera).

Photo 13–10. The result of severe leaf distortion and necrosis due to flumioxazin (e.g., Valtera) in soybean.

Chloroacetamides (Group 15)
(systemic – xylem mobile)
(e.g., Dual ll Magnum, Frontier Max, Pyroxasulfone 85 (found in Authority Supreme, Fierce and Focus))

- stunting of shoots resulting in abnormal seedlings that do not emerge
- impact on yield will depend on severity of injury and crop stage at time of injury but is typically minor or non-existent

Grassy Plants
- grasses may leaf-out underground
- shoots may be abnormal when leaves do not properly unfurl (Photo 13–11)

Broadleaf Plants
- crinkled leaves and/or shortened mid-vein, which produces "draw-string" effect or heart-shaped leaves (Photo 13–12)
- dry edible beans will show yellowing of lower leaf margins that will turn necrotic (brown), new growth will be unaffected. (Photo 13–13). In extreme cases, necrosis will be so severe it removes lower leaves and the only green growth is from new leaf tissue (Photo 13–14).

Photo 13–11. Abnormal shoot growth caused by an inability to unfurl after an application of a chloroacetamide (e.g., Dual II Magnum) herbicide.

Photo 13–12. S-metolachlorbenoxacor (Dual II Magnum) injury in soybean, showing the characteristic drawstring effect that gives a heart-shaped leaf appearance.

Photo 13–13. Yellowing of lower leaf tissue caused by excessive uptake of a chloroacetamide herbicide (e.g., Dual II Magnum) after a heavy rainfall.

Photo 13–14. A worst case of chloroacetamide (e.g., Dual II Magnum) injury in edible beans. The injury is so great; the lower leaves are removed, leaving only the newest leaf growth. This plant recovered fully.

Injury Affecting Older Leaf Tissue (with the potential to move upward)

Systemic photosynthetic inhibiting herbicides (systemic – xylem mobile)

Triazines (Group 5)
(e.g., Atrazine, Sencor, Princep Nine-T)
Substituted ureas (Group 7)
(e.g., Lorox)

- translocation occurs only in the xylem (upwards movement only)
- injury symptoms occur after the cotyledons and first true leaves emerge
- injury begins with yellowing of the leaf margins or tips and yellowing between the leaf veins (Photo 13–15)
- older and larger leaves are affected first (Photo 13–16)
- injured leaf tissue eventually turns brown and dies (Photo 13–17)
- injury is greater on higher pH soils (>pH 7.2)
- impact on yield will depend on the severity of injury and the crop stage at which the injury occurred

Photo 13–15. Soybean response to atrazine residues. Note the lower leaf margins turn yellow. Yellowing then moves to the inner part of the leaf. The yellow leaf tissue will eventually turn brown.

Photo 13–16. Linuron (Lorox) injury in soybeans causing necrosis (browning) of the lower leaves while the new growth is unaffected.

Photo 13–17. Soybean response to Metribuzin (e.g.,Sencor) splash. Note the severe browning that affects more of the lower leaf tissue. Injury Limited to Plant Tissue Exposed at the Time of Application and With No Movement to New Plant Growth.

Non-systemic photosynthetic inhibiting herbicides (Group 6)
(contact)
(e.g., Basagran, Pardner)

- injury is confined to foliage that has come in contact with herbicide
- crop oil concentrates and other additives may intensify injury symptoms
- injury is typically cosmetic with little to no impact on yield

Grassy Plants
- grass plants are generally tolerant to the non-systemic photosynthesis inhibitors. The exception would be when bromoxynil (Pardner) is applied prior to the 4-leaf stage of corn (Photo 13–18)

Broadleaf Plants
- typical symptoms include leaf speckling, blotching or bronzing and leaf tip burn (Photos 13–19 and 13–20)

Phosphorylated amino acids (Group 10)
(contact with limited phloem and xylem mobility)
(e.g., Liberty, Ignite)

- chlorosis and wilting usually occur within 3–5 days followed by necrosis within 1–2 weeks
- symptoms occur faster in bright sunlight and high humidity
- impact on yield is typically significant (Photos 13–21 and 13–22)

Photo 13–18. Bromoxynil (e.g., Pardner) leaf tissue burn on corn.

Photo 13–19. Bentazon (e.g., Basagran Forte) injury in soybeans.

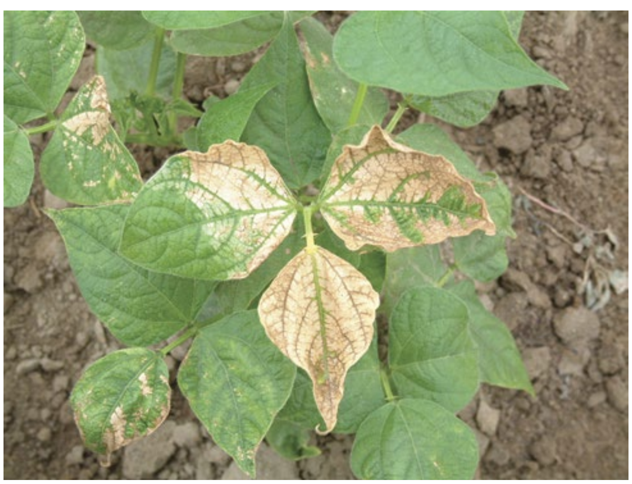

Photo 13–20. Bentazon (e.g., Basagran Forte) injury in white beans.

Photo 13–21. Browning and reddening of exposed leaf tissue caused by off-target glufosinate (e.g., Liberty) drift. Note the new leaf tissue is unaffected.

Photo 13–22. Severe leaf necrosis (browning) caused by accidental application of glufosinate (e.g., Liberty) onto cranberry bean.

Diphenylethers (Group 14)
(contact) (e.g., Reflex, Blazer, Eragon, Valtera)

- reddish-bronze spotting of the leaf surface may appear shortly after application (Photo 13–23)
- spotting is highly correlated to the spray application pattern (Photo 13–24 and Photo 13–25)
- plants that do not die may be stunted for a week or so
- crop oils and other additives may increase plant injury (Photo 13–26)
- injury to labelled crops is typically cosmetic, with little to no impact on yield

Photo 13–23. Reddish-bronze speckling on soybean leaves caused by application of fomesafen (e.g., Reflex).

Photo 13–24. A tank contaminated with a low rate of fomesafen (e.g., Reflex) applied to corn.

Photo 13–25. Corn leaf tissue response to fomesafen (e.g., Reflex). Note the severe necrosis that causes a fusing of the newest leaf tissue, obstructing normal development of subsequent vegetation.

Photo 13–26. Injury caused by diphenylether herbicides (e.g., Blazer) can be more severe when crop oils and other additives are added.

Bipyridiliums (Group 22)
(contact)
(e.g., Reglone, Gramoxone)

- injury occurs very quickly (1–2 days after application) (Photo 13–27)
- plant leaves will have a limp, water-soaked appearance, followed by browning of the leaf tissue (Photo 13–28)
- drift injury appears as blotching necrotic regions on leaf tissue (Photo 13–29)
- impact on yield can be significant
- perennial plants affected will grow back

Additives (No specific group)
Surfactant or 28% UAN injury

- typically causes severe browning of leaf tissue but can cause a blotchy light green to yellow (Photo 13–30)
- new leaf tissue will be unaffected
- most common with 28% UAN used as a carrier to apply herbicides in cereals or when an excessive rate of surfactant is used (Photo 13–31)
- largely cosmetic injury with negligible yield loss, provided visual injury is not severe

Photo 13–27. Diquat (e.g., Reglone) injury as a result of off-target drift onto field corn.

Photo 13–28. Severe corn leaf tissue damage following an accidental application of diquat (e.g., Reglone). Provided the corn plant's growing point is still below ground (prior to the V6 stage), a plant will survive.

Photo 13–29. Diquat (e.g., Reglone) injury as a result of off-target drift onto soybean.

Photo 13–30. Surfactant injury to soybeans.

Photo 13–31. Leaf tip burn (necrosis) on cereals that can be caused by many things (e.g., frost, surfactants) but in this photo is caused by 28% UAN as a carrier with a herbicide application.

Injury Affecting New Growth and With the Potential to Move From Leaves to Roots

Lipid synthesis (ACCase) inhibitors (Group 1)
(systemic – phloem mobile)
(e.g., Assure ll, Excel, Poast Ultra, Venture)

- newer leaf tissue typically will be yellow or red, then turning brown; the leaves in the whorl will be decomposed and easy to pull out (Photo 13–32 and Photo 13–33)
- symptoms develop slowly (7–14 days)
- impact on yield is significant

Grassy Plants

- injury on grass plants only, no activity on broadleaf plants

Amino acid synthesis inhibitors (Group 2)
(systemic – phloem mobile)
(e.g., Accent, Classic, Pinnacle, Pursuit, Ultim)

Grassy Plants:
- internodal stunting, distorted leaf tissue, yellowing and purpling of leaf tissue (Photo 13–34 and Photo 13–35)

Broadleaf Plants:
- internodal stunting
- leaf distortion with interveinal yellowing
- underside of leaf may have red, brown or purple veins (Photo 13–36)
- symptoms take 1–2 weeks to develop
- impact on yield will depend on the severity of injury and crop stage at which the injury occurred

Photo 13–32. Stunting, yellowing and reddening of corn leaf tissue caused by a lipid synthesis inhibitor (e.g., Assure II, Excel).

Photo 13–33. At 5–10 days after application with a graminicide (e.g., Assure II) the newest leaf should pull out of the whorl very easily and expose a brown decomposed end.

Photo 13–34. Corn response to imazethapyr (e.g., Pursuit) drift. Note the distortion and reddening or purpling of the leaf tissue.

Photo 13–35. Sulfonylurea (e.g., Option, Ultim) injury to corn where symptoms include distortion and yellowing of the new leaf tissue.

Photo 13–36. Distortion and yellowing of leaf tissue caused by a group 2 (e.g., Classic) herbicide. Note the prominent brown veins on the underside of the leaf.

Growth regulators — (Group 4 – phenoxy acids)
(systemic – phloem mobile)
(e.g., 2,4-D, 2,4-DB, MCPA, MCPA/MCPB)

- broadleaf plants exhibit stem twisting and leaf malformations (cupping, crinkling, parallel veins, leaf strapping)
- 2,4-D will lengthen petioles of trifoliate soybean leaf (Photo 13–37 and Photo 13–38), whereas benzoic acid herbicides (i.e., Banvel ll) will often cause cupping (Photo 13–39)
- corn plants exhibit rolled leaves (onion leafing) (Photo 13–40), fused brace roots (Photo 13–41), stalk bending (goose necking) and brittleness (Photo 13–42), and missing kernels
- small grains exhibit twisted flag leaves, sterile florets or multiple florets, twisted awns and head malformation (Photo 13–43)
- impact on yield will depend on the severity of injury and crop stage at which the injury occurred

Growth Regulators — (Group 4 – benzoic acids)
(systemic – phloem mobile)
(e.g., Banvel ll, Distinct)

- dicamba injury is similar to that caused by phenoxy acid herbicides
- broadleaf plants may exhibit more cupping than strapping of leaf tissues (Photo 13–44)
- will cause more goose necking than 2,4-D in corn and lodging in small grain (especially wheat)
- impact on yield will depend on the severity of injury and crop stage at which the injury occurred

Growth Regulators — (Group 4 – pyridine acids)
(systemic – phloem mobile)
(e.g., Lontrel, Milestone)

- injury similar to phenoxy and benzoic acid herbicides
- legume crops (soybeans, alfalfa, clovers) are extremely susceptible to the pyridine acids
- impact on yield-sensitive species is significant

Photo 13–37. 2,4-D injury that mottles and lengthens the soybeans' trifoliate leaf. New growth is typically unaffected.

Photo 13–38. 2,4-D injury can be differentiated from dicamba injury by the elongated petiole of the trifoliate leaf, the bubbling of leaf tissue and narrowing of trifoliate leaves.

Photo 13–39. Soybean leaf cupping caused by off-target dicamba (e.g., Xtendimax) drift.

Photo 13–40. Onion leafing in corn caused by growth regulating herbicides, in this case dicamba (e.g.,Banvel II).

Photo 13–41. Fused brace roots caused by growth regulating herbicides. Injury risk is greatest when a high rate is applied beyond the labelled corn leaf stage and to sensitive hybrids.

Photo 13–42. Brittleness and lodging caused by MCPA that was applied at the 7–8 leaf stage of corn which was well past the labelled stage of 4–leaf corn.

Photo 13–43. Twisting and distortion of winter wheat heads from a pre-plant application of 2,4-D applied in the fall.

Photo 13–44. Glyphosate drift onto non-tolerant soybeans. Note the newest leaf tissue is yellow, a characteristic symptom of glyphosate injury to plants.

Aromatic amino acid synthesis inhibitors (Group 9)
(systemic – phloem mobile)
(e.g., Roundup, Weathermax, Touchdown Total)

- plant foliage will first yellow (new leaves first) (Photo 13–44), then turn brown and die within 10–14 days after herbicide application
- drift onto corn can cause reddening of leaf tissue
- impact on yield is significant
- injury to glyphosate-tolerant corn hybrids is extremely rare but can happen when very high rates are applied. The injury is usually a mild “V-shape” of transparent leaf tissue surrounded by necrosis (browning) (Photo 13–45)

Pigment inhibitors (bleaching herbicides) triazoles (Group 11)
(e.g., Amitrol 240)
Inhibitors of carotenoid biosynthesis (Group 13)
(e.g., Command)
HPPD inhibitors (Group 27)
(e.g., Callisto, Converge, Impact, Infinity)

- injury begins with new leaf tissue turning a white "bleached" colour then progressing to yellow, followed by brown necrotic tissue
- impact on yield is generally minor, but if injury is severe, it can be significant (Photo 13–46, Photo 13–47 and Photo 13–48)

Photo 13–45. Glyphosate injury on glyphosate tolerant corn caused by very high rates.

Photo 13–46. Soybean response to mesotrione (e.g., Callisto) drift with the characteristic bleaching of new leaf tissue. This tissue will turn yellow, then brown.

Photo 13–47. Bleaching of a spring cereal crop due to clomazone (e.g., Command) carryover. Leaf tissue turns white to pinkish-purple, then browning. Most of the whitened leaf tissue will not fully recover.

Photo 13–48. Bleaching injury to corn, caused by an overlap rate and inclusion of a non-labelled adjuvant.

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[5] **Figure 13–2. Typical yield losses of different field crops due to weed competition.**

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