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The undercover benefits of inoculants.

The role of biological nitrogen fixation in an agricultural system.
Written by: Allison Friesen

Nitrogen. A vital element.

As a grower, when you think of nitrogen the words fertilizer, availability and essential come to mind. But why is nitrogen so important and why do your crops need it to survive? Nitrogen is a fundamental element for plant growth, development and reproduction. It's so vital because it's a major component of chlorophyll, the pigment plants use to convert sunlight energy to produce sugars from carbon dioxide and water. It's also a major component of amino acids, which are the building blocks of proteins. But despite being one of the most abundant elements on earth, it's not directly available to plants and can only be taken up in certain forms. This is why nitrogen deficiency is one of the most common nutritional problems in plants. Plants can receive the usable forms of nitrogen (typically ammonium and nitrate) from several sources (Figure 1):

1. The addition of ammonia and/or nitrate fertilizer (The Haber-Bosch process)
2. Organic matter decomposition
3. The conversion of atmospheric nitrogen by natural processes (e.g. lightning)
4. Biological nitrogen fixation

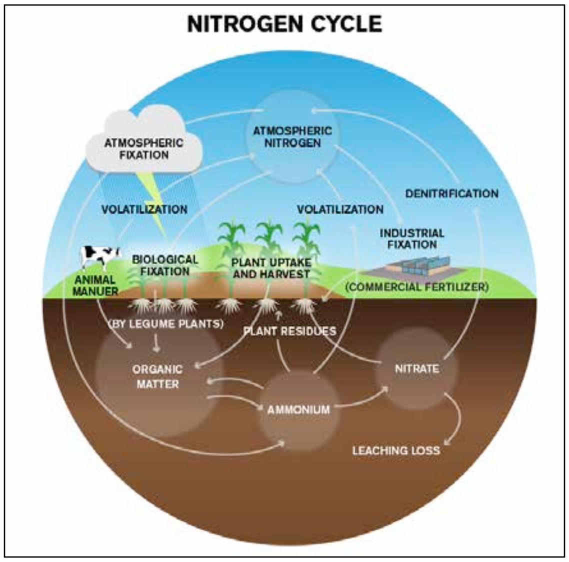

Figure 1. The nitrogen cycle.
Source: http://www.cropnutrition.com/efu-nitrogen

The process

Biological nitrogen fixation is carried out by a specialized group, collectively referred to as plant-growth promoting microorganisms (PGPM). Some examples include *Rhizobium, Bradyrhizobium, Azotobacter* and *Azospirillum*. The conversion of nitrogen from the atmosphere (N_2) requires a lot of energy because of its extremely strong bond. Symbiotic nitrogen-fixing PGPMs like *Rhizobium* and *Bradyrhizobium* obtain this energy from the rhizosphere (or the area surrounding the roots) of legume crops. They then use the enzyme nitrogenase to break the strong bond and drive the conversion of atmospheric nitrogen into ammonium (NH_3/NH_4^+), a form of nitrogen that can be readily taken up by the plant.

Why we need rhizobia.

It's estimated that approximately 80% of fixed nitrogen on the planet is due to the activity of rhizobia bacteria. It's also estimated that the rhizobium-legume association is responsible for producing 35 million tons of nitrogen annually (Sassitsch et al. 2002). Inoculants take advantage of the unique and mutually beneficial relationship between legumes and rhizobia to make nitrogen available for use by the plant. These rhizobia are located in nodules on the plant's roots (Figure 2) and convert atmospheric nitrogen into ammonium and in return, the plant provides the rhizobia with energy, water and nutrients. The overall result is enhanced plant growth and nutrient uptake, resulting in increased yield potential.

Figure 2. Nodule formation on peas.

The "other" inoculant benefits.

The fact that inoculants enhance crop growth is the most attractive feature which drives their incorporation into pulse production. But inoculants actually provide several other environmental benefits that often go unnoticed. As more inoculants are being made commercially available, there has been a substantial reduction in fertilizer use. Overuse of fertilizers has led to an upset in the nitrogen cycle causing surface water and groundwater pollution. Environmental pollution from fertilizer nitrogen escaping root zones is high because fertilizers are not used efficiently by crops (Sessitsch et al. 2002). In general, 60 to 90% of total applied fertilizer is lost and only the remaining 10 to 40% is taken up by plants (Bhardwaj et al. 2014). Biological nitrogen fixation offers more flexible management compared to fertilizers because the pool of nitrogen becomes more slowly available. This is ideal for the current legume crop but it's also convenient for future rotations of non-legumes. Research shows that when cereals are grown on field-pea stubble, they produce more yield per acre than cereals grown on canola stubble (Canola Council of Canada). Because of these yield benefits, legumes are often not grown as continuous crops but are rotated with non-legumes like cereals or oilseeds.

But the benefits don't end there. Not only do inoculants fix nitrogen and enhance plant growth, they also promote other beneficial nitrogen-fixing bacteria in the soil, increase the supply of other essential nutrients and they can provide control of bacterial and fungal diseases. On top of that, inoculants can also increase the stability and fertility of the soil, particularly in poor environments. Below is a summary of the benefits inoculants provide to both the crop and the surrounding environment.

- Improve fixation of nutrients in the soil
- Provide food supply for growth of microorganisms, including earthworms
- Increase soil stability, structure and root growth
- Promote decomposition and increase organic matter levels in the soil
- Promote the development of beneficial fungi like mycorrhiza
- Produce growth stimulants for the plant
- Enhance other beneficial bacteria and fungi
- Encourage processes to remove toxins from contaminated soils

Conclusion.

Inoculants and the plant-growth promoting microorganisms they utilize play an important role in agriculture. Especially since increased inoculant use can reduce reliance on fertilizers and other chemicals. Overall, inoculants can improve productivity in a relatively short amount of time, increase soil fertility, mitigate soil contamination and promote biological control of pathogenic organisms. With an increasing global demand for protein-rich crops, inoculants will continue to play an important role in sustainable agriculture.

Sources.

Bhardwaj, Deepak, Wahid Ansari, Mohammed, Kumar, Ranjan, and Tuteja, Narendra. 2014. Biofertilizers function as a key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. Microbial Cell Factories. 13:66.

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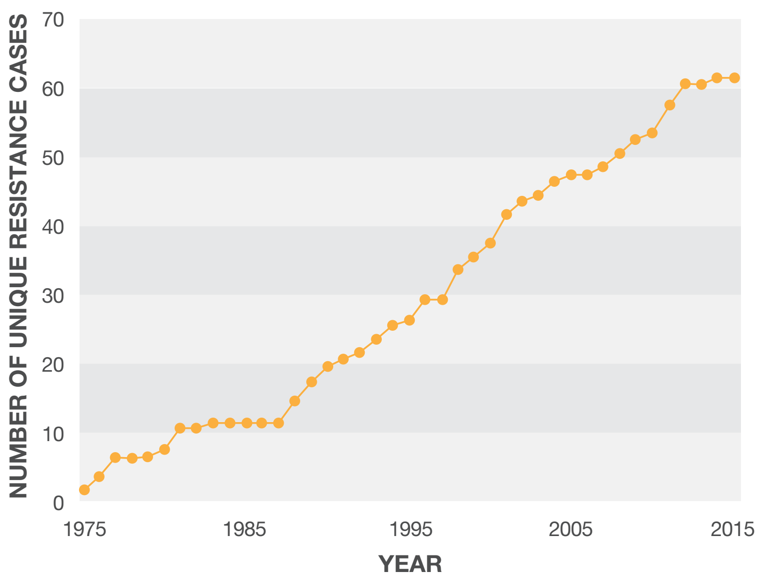
Weed control in pulses is all in the planning.

Taking an integrated approach to resistance management in pulses.
Written by: Paula Halabicki

When it comes to weed control, pulse crops can be high maintenance – but done right, they can be worth every penny. As growers are aware, pulse crops are non-competitive in nature. That's why herbicides have been essential in preventing losses to yield and quality. But pulse crops are also sensitive to many modes of action, relying mainly on Group 2 chemistry for in-crop weed management. Widespread use of Group 2 herbicides in pulses and many other crops has led to a sharp rise in herbicide resistance. Today, 19 out of 20 resistant weed species in the Prairies have confirmed resistance to Group 2 chemistry, including wild mustard, kochia and cleavers.[1]

Increase in unique resistant weed cases in Canada



Source: Heap, I. 2016. WeedScience.org.[1]

Top 10 weeds by province.

Rank	Alberta (2010)	Saskatchewan (2014/2015)	Manitoba (2016)
1	**Wild buckwheat**	**Green foxtail**	**Green foxtail**
2	**Wild oats**	**Wild oats**	Wild buckwheat
3	**Cleavers**	Wild buckwheat	Barnyard grass
4	Canada thistle	**Volunteer canola**	**Wild oats**
5	Dandelion	Canada thistle	**Volunteer canola**
6	**Volunteer canola**	Spiny annual sow thistle	Yellow foxtail
7	**Chickweed**	**Cleavers**	Dandelion
8	Lamb's quarters	**Lamb's quarters**	**Redroot pigweed**
9	**Stinkweed**	Narrow-leaved hawk's beard	Volunteer spring wheat
10	**Hempnettle**	Dandelion	Round-leaved mallow

Bold = Known populations of Group 2 resistance.

Sources: Adapted from various sources.[2,3,4]

This has already led to serious consequences for our farming operations. If left unchecked, we could lose the use of Group 2 chemistry altogether. This limits our options for weed control, especially for pulse crops, and can raise the cost of production. Fortunately, we can manage current resistance problems and mitigate future issues by taking an integrated approach – one that includes both herbicidal and non-herbicidal strategies.

The key is planning ahead.

Rather than focusing on the pulse season alone, step back and look at your production plans over a period of several years. Are you selecting more competitive rotational crops? Are you rotating your herbicidal modes of action within and between seasons? Are you controlling weeds post-harvest or pre-seed/pre-emergence? Are you using multiple modes of effective action? These are all strategies that can help you conserve Group 2 use for the future.

Pre-season decisions.

Up the competition with rotational crops.

Growing a more competitive rotational crop in the previous season(s) will help control weeds ahead of time and reduce weed pressure. Choose a crop whose volunteers can be managed relatively easily in the pulse year. Good options include cereals and (non-Group 2) herbicide-tolerant canola.

Save your Group 2s for pulses.

Use Group 2 herbicides no more than once per season and avoid applying in consecutive seasons. Use alternative modes of action for rotational crops wherever possible. Depending on the pulse crop grown and the soil type, Group 2 carryover and stacking can be an issue. Take note of this before applying another Group 2 herbicide, as crop injury can occur with built-up residues.

Set yourself up for success.

Fall is the best time to control winter annual, biennial and perennial weed species. In the year prior to growing pulses, consider using a multiple-mode-of-action tank mix of glyphosate and a non-Group 2 post-harvest herbicide. This makes for a cleaner start the following spring.

In-season decisions.

Anticipate weeds. And which ones.

Keep records of weed species and patches. Choose herbicidal modes of action that will be effective on anticipated weeds. Avoid planting pulses in fields known to harbour perennials, biennials or Group 2-resistant biotypes.

Variety matters.

Choose more competitive pulses and varieties. Dr. Chris Willenborg at the University of Saskatchewan is looking at the competitiveness of different pea varieties and how this information can impact variety choice.[5] Consider the possibility of planting mixtures of highly competitive varieties with less competitive ones.

Seed early to increase competition.

Aim to seed late April or early May to give your crops a head start. Many pulse crops are more tolerant to early spring frosts than other crops. The growing points remain underground, so new shoots can still emerge from under the soil after a damaging frost event. Seeding at a higher rate and use of a seed treatment are recommended as germination and emergence can be affected by cool soil conditions.[5] Also consider narrower row spacing. Crop canopies in narrower rows are able to close faster and shade out weeds, but this will also reduce air flow and potentially impact disease development.

Critical periods for weed control.

The critical weed-free period for lentils is from the 5th to 10th node stages, while for peas it is from emergence to the 3rd node stage. Weed competition at this time will have the greatest impact on crop yield, stealing the nutrients, water and sunlight that your crop needs.

Layer your herbicides.

A pre-seed/pre-emergent burndown will provide early season control to start your fields off clean and can also address weeds that cannot be controlled later on in-crop. Tank mix products with contact and residual activity to burndown weeds and help take the pressure off your second pass. Even if residual products don’t provide complete control, they can reduce the size and number of weeds, making them easier to deal with in-crop. Ensure that your in-crop herbicide uses a mode of action that differs from your burndown – this can control a wider spectrum of weeds and help delay herbicide resistance. Also be sure to apply at correct label rates when weeds are small and actively growing to get the best efficacy. Research has shown that you can control up to 95% of weeds just by using a two-pass system.[5]

Use a harvest aid for weed control.

Late-season weeds can also affect yields, interfering with harvest and contributing to dockage, staining and moisture in storage – this is where a harvest aid comes in handy. Use it to control weed escapes and clean up perennials. Plus, it helps dry down your crops and weeds for an easier harvest.

Year-round considerations.

Use multiple modes of action.

Research has shown that using tank mixes or products containing multiple modes of effective action has a greater impact on delaying herbicide resistance than rotating single modes of action.[5] That's because it's unlikely for a weed to develop resistance to more than one mode of action at once. If it escapes control from one mode, it will likely be controlled by the other, thus preventing it from reproducing and adding to the resistant population. If resistant weeds already exist, be sure to incorporate two or more modes of action that each provide control. Remember to always check that mixtures have overlapping weed spectrums, otherwise you might be depending on only one active ingredient and inadvertently screening for resistant weeds.

Keep an eye out for resistance.

Scout regularly and take note of weed populations both before and after any herbicide application. This will help identify problematic weeds and possible cases of resistance early, while you can still make an impact. Send any suspected resistant weeds for testing, and use roguing, mowing or weed wicking to prevent resistant weeds from setting seed.

Herbicide resistance management in pulses doesn't mean giving up your Group 2 herbicides. Plan your herbicide use in advance and take an integrated approach using both chemical and non-chemical strategies. That's the key to good herbicide stewardship and delaying the onset of herbicide resistance on your farm.

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Using your Group 2's wisely.

Strategies for managing Group 2 resistance in pulses.
Written by: Bryce Geisel

Herbicide resistance is particularly challenging for pulse crops. Not only are they poor competitors to weeds, pulses are more limited in herbicide options than many other crops. As a result, they rely almost exclusively on Group 2 herbicides for in-crop broadleaf control. This is an issue when some of the most prevalent weeds in Western Canada have known populations of Group 2 resistance, including wild mustard, kochia, cleavers, lamb's quarters and stinkweed.[1]

Reported populations of resistant weeds in Canada.

Weed	Herbicide group resistance ("+" indicates multiple resistance)		
	Alberta	**Manitoba**	**Saskatchewan**
Ball mustard	2	-	-
Common chickweed	2	2	2
Common hempnettle	2, 4	2	-
Common lambs-quarters	-	-	2
Cowcockle	2	-	-
Cleavers	2+4,	2	2
Stinkweed	2	2	2
Green foxtail	1, 3	1, 2, 3, 1+3	1, 3, 1+3
Kochia	2, 2+9	2, 2+9	2, 2+4, 2+9
Narrowleaf hawksbeard	2	-	-
Pale smartweed	2	2	-
Persian darnel	1	-	1
Powell amaranth	-	2	-
Redroot pigweed	-	2	2
Russian thistle	2	-	2
Shepherd's purse	2	-	2

Spiny sowthistle	2	-	-
Wild buckwheat	2	-	-
Wild mustard	2	2, 4, 5	2
Wild oats	1, 2, 8, 1+2+8	1, 2, 8, 1+2+25, 1+2+8+25, 1+2+8+14+15	1, 2, 8, 1+2+8

Source: Heap, I. The International Survey of Herbicide Resistant Weeds.[1]

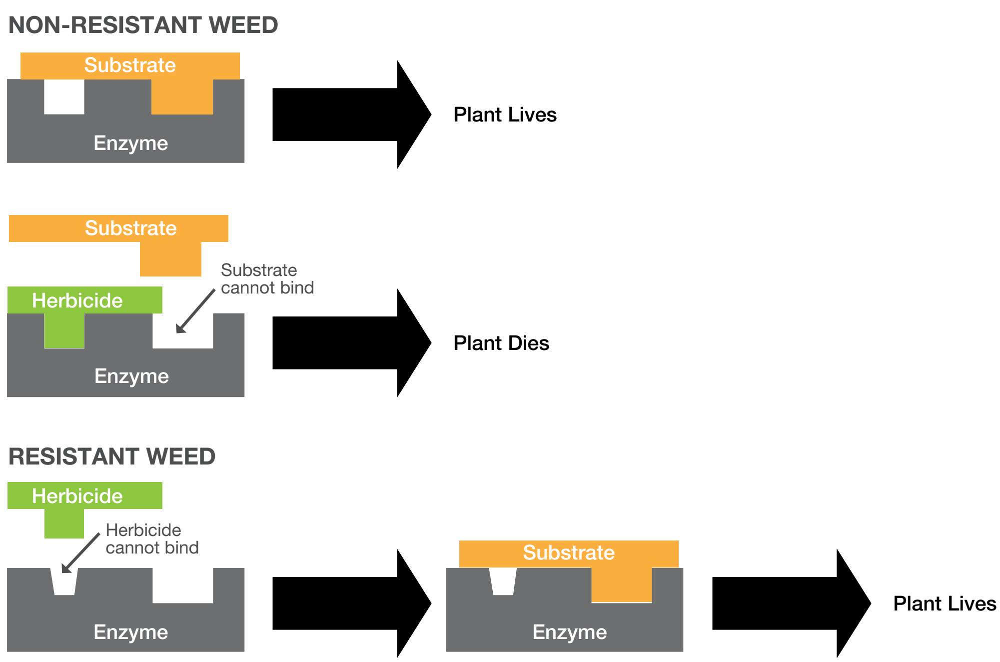
How resistance comes about.

Herbicides work by inhibiting important enzymes or processes key to a weed's survival. This is known as the "mode of action". Herbicides that target the same enzymes or plant processes (e.g. photosynthesis) are given the same Group number. For instance, herbicides that fall under Group 2 all target the acetolactase synthase (ALS) enzyme responsible for producing amino acids. This is essential to plant growth and development.

Weeds resistant to herbicides contain natural, genetic variations that make the herbicide ineffective. This will occur in a weed population regardless of whether a herbicide is applied or not. The most common one is a result of one or more mutations to the herbicide's target enzyme. It changes the enzyme, preventing the herbicide from binding and allowing the pathway to continue uninterrupted, resulting in continued plant growth. With Group 2-resistant weeds, the mutation is in the ALS enzyme.[2] The structural change only prevents the herbicide from binding and doesn't affect enzyme function itself, allowing the weed to continue to grow and develop.

Once resistance appears, continued use of the same herbicide or herbicide Group will only screen for resistant weeds and eliminate the susceptible ones. Unless another mode of action is introduced, the resistant ones will continue to grow and set seed, increasing the resistant population until they eventually dominate the field. Weeds that remain actively growing after a herbicide application amongst controlled weeds of the same species warrant further scrutiny beyond the assumption of a sprayer miss. This could be the start of herbicide resistance in that field.

Target-site resistance visualized

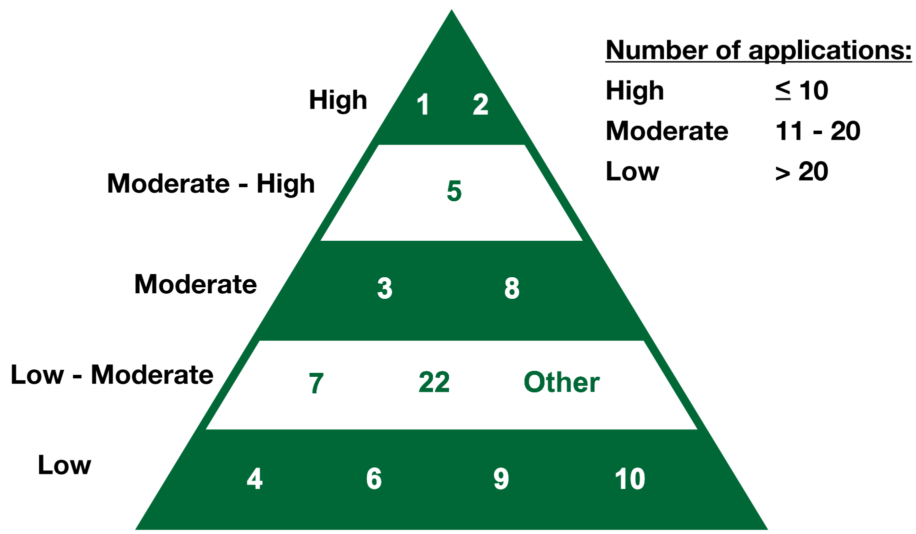


Source: Adapted from Beckie, H. 2009. Herbicide resistance update.

How quickly resistance spreads.

As it turns out, the risk of developing resistance depends on the herbicidal mode of action. Researchers have classified this risk based on the number of applications it takes to select for resistance. For Group 2 herbicides, the risk is incredibly high as fewer than 10 herbicide applications are enough for a weed with resistance to show up in a field.[3] That's because plants have several naturally occurring forms of the ALS enzyme,[4] and all it takes is a random mutation in one gene to develop resistance. In other words, Group 2-resistant weeds occur more frequently than most other Groups in any given field. So the more Group 2 herbicides are used, the more likely you are to come across a resistant weed.

Herbicide Resistance Development Risk Based on Number of Applications



Source: Saskatchewan 2016 Guide to Crop Protection. Adapted from: Beckie, H.J. 2006.[3]

Certain weeds are also more likely to develop resistance to herbicides. These weeds typically produce large amounts of seed with high levels of genetic diversity. Because of their short lifecycle and high levels of seed production, annual weeds are particularly prone to resistance.

Conserving Group 2 chemistry

Group 2 chemistry is one of the most important herbicide Groups used, having products applied in cereals, canola, and soybeans in addition to pulse crops. The more Group 2 resistance continues to spread, the fewer herbicide options we have. Plus, it limits cropping decisions as pulses have few options of other chemistries. If resistance isn't kept in check, the need for multiple chemistries will lead to higher costs.

Targeting Group 2 resistance is two fold: managing existing resistant weeds and preventing the onset of further resistance. That's not to say farmers have to stop using Group 2 chemistry altogether – it just needs to be managed. To conserve the use of this chemistry, consider the following best practices:

Break out the Group 2 herbicide once per season

Even though different products within the same group may target different weeds, the underlying chemistry is similar. Simply rotating into a different product or brand that belongs to the same herbicide group will not help prevent herbicide resistance. Rotate into alternative modes of action within a season and avoid applying Group 2 herbicides in consecutive seasons.

Apply multiple modes of action with overlapping weed spectrums

This prevents selection pressure from one active ingredient. For instance, Group 1 herbicides do not effectively control cleavers. Used in a tank mix with a Group 2 herbicide, the application ultimately relies on Group 2 action and selects for Group 2-resistant cleavers. For MMOA to be an effective strategy, active ingredients must have overlapping weed spectrums so resistant weeds aren't given an opportunity to set seed. If Group 2 resistance already exists in your fields, ideally two other modes of action will be used to avoid selecting for multiple resistance.

Conserve your Group 2's

Wherever possible, use non-Group 2 herbicides in other crop rotations. This will help save Group 2 products for when there are few other options, like pulse crops.

Layer your herbicides

Consider rotating your herbicidal modes of action in your two-pass approach. Start your fields off clean with an effective burndown, and choose a product with residual activity to keep weeds small for the in-crop herbicide. The pre-seed burndown will take care of any emerged weeds, while your residual activity and in-crop herbicides can be used to target flushing or later emerging weeds.

In addition to sustaining Group 2 herbicides, be sure to take up other practices that can help manage herbicide resistance. This includes scouting before and after herbicide applications, using proper label rates and keeping detailed records of herbicides. Minimize weed seeds by planting certified seed, using clean equipment and establishing your crop early on to outcompete the weeds. Take an integrated approach to managing herbicide resistance, and help lengthen the effectiveness of all available chemistries.

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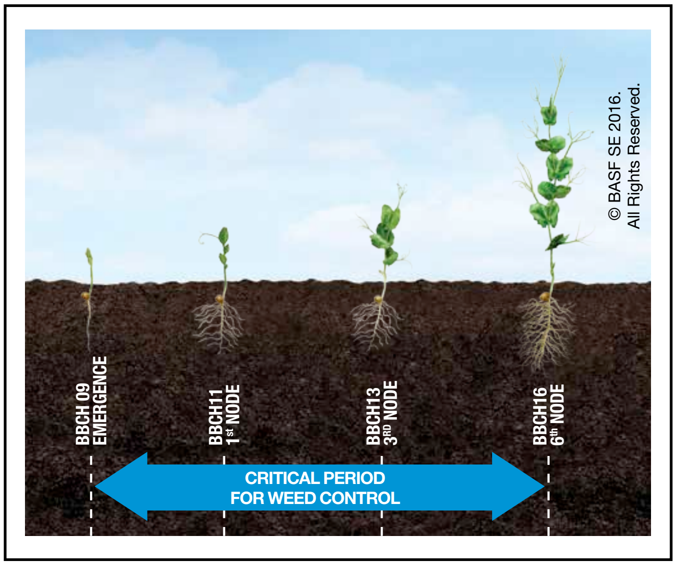
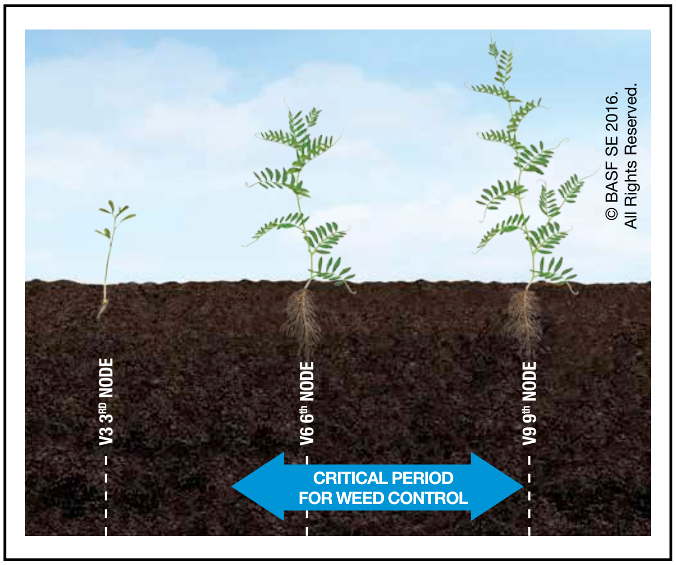
Weed management with peas and lentils.

A closer look at herbicides in your rotation.
Written by: Allison Friesen

Increasing diversity by incorporating pulses in your rotation has a number of well-established benefits in terms of disease management, soil conservation and weed control. When including crops like peas or lentils, it is important to carefully consider your available herbicides and how those choices can be best integrated with the bigger picture of weed management. Both crops are relatively non-competitive, especially in their early stages just after emergence. A plan that ensures weed control through their critical periods of early development is essential for preserving early gains in yield potential. Herbicide choices both before and after the pulse crop also need to be considered in terms of resistance management and crop safety. So how do you put it all together?



Critical period of weed control in peas.



Critical period of weed control in lentils.

Herbicide application options for pulses

A good first step is to understand the differences between pre-seed, pre-emergent, and in-crop herbicide applications.

- Pre-seed applications are made on weeds that are actively growing before the field is seeded
- Pre-emergent applications are made after seeding but before the crop has emerged
- Both pre-seed and pre-emergent applications can have burndown and residual activity to control emerged weeds and prevent others from germinating, before the crop appears
- In-crop applications are made after the crop has emerged to control later germinating weeds during the crop's early development

For early weed control, pre-seed applications are generally recognized as the most ideal option for pulses as there several modes of action available. If you are unable to make a pre-seed application, pre-emergent herbicide applications are still an option, however it is important to refer to the label for any restrictions to avoid possible injury to the emerging plants.

A tank mix of glyphosate with a Group 14, applied pre-seed or pre-emergence is a great option to control actively growing weeds through two modes of action. This is especially important for resistance management on weeds like kochia, wild mustard and volunteer canola.

In-crop herbicide options

Peas

Following the pre-seed application with an in-crop application of a multiple-mode-of-action herbicide registered for peas (e.g. Groups 2,6) helps to clean up any later germinating weeds. This helps keep the crop weed-free until it is well established and also reduces the weed seed pressure for the next season. The Group 6 also provides another mode of action for the resistance management plan.

Lentils

Conventional lentils are very sensitive to most herbicides. Post-emergent options are typically limited to Groups 5 and 1 herbicides applied when the plants are small. If you are growing a herbicide-tolerant crop like **Clearfield®** lentils, in-crop applications are open to alternative Group 2 chemistries, as well as the Group 1 and 5.

Fall herbicide choices

Pulse crops can be sensitive to herbicide residues, especially in drier years. To avoid crop injury, it is important to be careful when planning the sequence of crops and the herbicides used two or three years prior to growing peas or lentils. Keep a record of the previous herbicides used in that field and be sure there are no restrictions for seeding your pulse crop when the time comes.

Reducing the risk of resistance

With the extensive use of glyphosate in production, there is a risk that several weeds could develop resistance to its Group 9 chemistry. To help preserve glyphosate's future utility, it is recommended that it be tank-mixed with alternative modes of action when using it for pre-seed or per-emergent applications.

Repeated use of herbicides using the same group chemistry will eventually select for weeds that are resistant to those herbicides. It is therefore important to plan rotations that include as much diversity in the herbicide group chemistries as possible. Weeds such as cleavers, kochia, wild mustard and wild oat have populations that are resistant to Group 2 herbicides (wild oat has been found to be resistant to Group 1 as well). The recommendation is to use herbicides other than Group 1 and 2, especially in years where other crops, like cereals, are in the rotation. BASF recommends using Group 2 herbicides no more than twice in a 4-year period and never twice in the same year.

Herbicide-resistant weeds in Western Canada

Resistant Weed	Herbicide Group
Ball mustard	2
Chickweed	2
Cleavers	2, 4 Combinations of 2 & 4
Cow cockle	2
Green foxtail	1, 2, 3 Combinations of 1 & 3
Hemp-nettle	2, 4
Kochia	2, 4, 9 Combinations of 2 & 9 Combinations of 2 & 4
Lamb's quarters	2
Narrow-leaved hawk's beard	2
Persian darnel	1
Powell amaranth	2
Redroot pigweed	2
Russian thistle	2
Shepherd's purse	2
Smartweed	2
Spiny sowthistle	2
Stinkweed	2
Wild buckwheat	2
Wild mustard	2, 4, 5
Wild oat	1, 2, 8 Combinations of 1 & 2 Combinations of 1 & 8 Combinations of 2 & 8 Combinations of 1, 2 & 8 Combinations of 1, 2 & 25 Combinations of 1, 2, 8 & 25 Combinations of 1, 2, 8, 14 & 15

Source: Adapted from the 2016 Crop Protection Guide, Government of Saskatchewan and Heap, I. The International Survey of Herbicide Resistant Weeds. Available www.weedscience.org

There are a lot of good reasons to include a pulse, like peas or lentils, in your rotation plans. In addition to other benefits, it's also a good opportunity to gain perspective on herbicide use and how your choices can be optimized for the best results in weed management.

Always read and follow label directions.