Soil Fertility and Crop Rotation Planning

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Understanding Crop Rotation and Crop Diseases

Crop rotation has an important role in an integrated approach to disease management. Diverse crop rotations can be used to break disease cycles and reduce pathogen levels and disease pressure between host crops. When the pathogen survives in the field (either in the soil or on infected crop residue), time away from a host crop will provide time for the infected crop residue to decompose and for the number of living pathogen spores or resting structures in the soil to decline. This means that there will be lower levels of the pathogen present to cause disease the next time a susceptible crop is grown.

Symptoms of the net form of net blotch of barley. Crop rotation away from cereals is an effective mitigation strategy to manage cereal leaf diseases.

Crop rotation as a disease management tool will have the most significant impact when:

- The disease has a narrow host range. This means there are more options to select non-host crops to add to the crop rotation to provide time for pathogen levels to decrease. For example, crop rotation is a very effective management strategy for diseases like blackleg, clubroot, ascochyta blight and aphanomyces root rot, as these diseases only infect a small number of major crops in Saskatchewan. On the other hand, crop rotation will be less effective for sclerotinia diseases, as the pathogen has the ability to cause disease in more than 400 plant types, including most of the broadleaf crops grown in Saskatchewan.

- The pathogen overwinters in the field (in the soil or on infected crop residue) and spore dispersal only occurs over short distances. When the pathogen overwinters in the field, strategies such as crop rotation can directly impact the amount of pathogen present to cause disease. However, when the pathogen is primarily introduced through other means, crop rotation may have less of an impact. An example of this is stripe rust of cereals. The stripe rust pathogen does not typically overwinter in Canada and the pathogen is often introduced to a field via spores carried on wind currents. Since the spores are introduced through an external source, crop rotation within a specific field will not impact disease levels in a given year.

The length of crop rotation needed will depend on how the pathogen survives in the field and the half-life of the spores or overwintering structures of the pathogen. As a general rule of thumb, a four-year crop rotation is recommended.

However, a three-year crop rotation can be very effective for some diseases (e.g: Fusarium head blight or clubroot) and a longer crop rotation is needed for others (e.g: aphanomyces root rot of pea and lentil, where an eight-year rotation is recommended).

The chart below illustrates some of the major and economically-important diseases of Saskatchewan crops and the major crop types that they can infect. This can be used to identify crop rotations that will provide adequate disease breaks to reduce pathogen levels and disease pressure.

Table 1. Important Diseases of Saskatchewan Crops.

		Pulses				Cereals				Oilseeds	
		Field pea	Lentil	Soybean	Chickpea	Durum	Wheat	Barley	Oat	Canola	Flax
Seed or soil-borne diseases	Seedling blights/root rot complex [a]	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green	Dark green
	Clubroot									Dark green	
	Aphanomyces root rot	Dark green	Dark green								
	Phytophthora root rot			Dark green							
Residue-borne diseases	Sclerotinia stem rot	Dark green	Dark green	Light green	Light green					Dark green	Light green
	Blackleg									Dark green	
	Cereal leaf spots [b]					Dark green	Dark green	Dark green	Dark green		
	Fusarium head blight					Dark green	Green	Light green	Pale green		
	Anthracnose		Dark green								
	Ascochyta blight [c]	Dark green	Dark green		Dark green						
	Pasmo										Dark green
	Brown spot			Dark green							

Colour Legend

Colour	Meaning
Dark green	Darker colours indicates that the disease is often considered economically important.
Green / Light green / Pale green	Lighter colours indicates that the disease may not always be economically important due to a combination of host genetics, plant architecture or other factors that influence disease development.

a. Caused by a complex of pathogens including *Fusarium, Rhizoctonia* and *Phythium* species. These organisms can cause disease in a broad number of host crops.
b. This includes all cereal leaf spots. Some leaf spot pathogens only cause disease in specific cereal crops.
c. Ascochyta blight in field pea, lentil and chickpea are caused by different *Aschochyta* species.

Rotation Effects on Insects

As in most years, we see heavy insect pressure in some crops. These range from the perennial issue of flea beetles in canola, localized wheat midge pressures and high grasshopper numbers in several crops. Localized insect pressures can be influenced by crop rotation, however their impact on the number of insect pests in subsequent years depends on a variety of factors.

Many insect pests in Saskatchewan are specialists. That is, through co-evolution with specific plant families and biochemical defenses that evolve to prevent insect feeding, their food choices are limited to closely-related plants that share a similar defense strategy. An example of this is the crucifer flea beetles, *Phyllotreta cruciferae*. This insect shared a co-evolutionary history with members of the Brassicaceae plant family, like canola. Defense compounds such as the breakdown of products in glucosinolates actually act as attractants to these beetles. They have evolved to get around potent defenses to take advantage of these hosts. Physical and biochemical properties of potential host plants influence the choices specific insects make.

Wheat midge adults are not strong flyers so populations tend to be localized. Continuous wheat production can contribute to increased wheat midge numbers.

Photo (c) Tyler Wist, AAFC

A "host" is a term to describe the suitability of a plant as food or a resource for the development of young insects. A "true host" allows the development of juvenile insects; a "food host" can be used by adult insects for nourishment, but will not support development. An example of this is the relationship of cabbage seedpod weevil (CSW) and members of the Brassicaceae family. Adult weevils will feed on a number of species within this plant family, but egg laying typically occurs and larvae can complete development on only a few member species. True hosts for CSW include canola and brown mustard; food hosts include weeds from the brassica family, like flixweed. This means that contributions to the population associated with larval development can contribute to next year's problems in another food host planted in the same area.

Although this seems like a good general approach to predicting problems, it can be confounded by two major factors: generalist feeding and insect movement, including to and from overwintering sites. Generalist feeding is not limited to one or two plant species, but insects can feed and develop on multiple plants within a family or even among members of multiple plant families. Examples of insects that employ this feeding strategy include the *Lygus* species and several of the grasshopper species that can be problematic in crops in Saskatchewan. Although generalists demonstrate preferences among plant species, they are capable of exploiting a broad group of potential hosts. Predictions based on last year's pressures can be problematic in these cases.

Many insects overwinter as adults and move into crops once activity begins in the spring. Some are also excellent flyers and can cover great distances to feed or lay eggs. This reduces the predictability of pressures based on last year's incidence. However, given a choice, many insects will limit their movement as much as possible, making preferred hosts near sites of adult emergence or deposition of eggs (in the case of those insects that overwinter as eggs or larvae), more susceptible.

Some local insect pressures are also strongly influenced by climate. For example, wheat midge overwinters in the ground as larvae and pupae. Survival and emergence of adults in the summer is poor if spring conditions are dry. Heavy local populations, followed by moist conditions the following spring, coupled with the presence of a suitable host like wheat can lead to problems. Grasshoppers are another example of populations influenced significantly by weather. In the case of most pest grasshopper species, moist conditions can contribute to outbreaks of fungal and bacterial diseases and are detrimental to population growth.

Crop rotation can affect insect pressure year to year but many caveats need to be considered. These include: the host range of specific pests, climatic effects and mobility of pests.

In general, rotation away from preferred hosts in subsequent years can be beneficial for controlling damage by many specialists. Work continues on increasing our understanding of the interaction of these factors.

Migratory Grasshopper

Table 2. Some Rotation Effects on Insects.

Crop Seeded	Brassica			Legume			Cereal		
Previous Crops	Brassica	Cereal	Legume	Brassica	Cereal	Legume	Brassica	Cereal	Legume
Flea beetles (primarily *Phyllotreta* spp)	Yellow	Blue	Blue	White	White	White	White	White	White
Redbacked cutworm	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Pale western cutworm	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Army cutworm*	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Delia spp. root maggots	Red	Green	Green	White	White	White	White	White	White
Lygus spp.	Blue	Blue	Blue	Blue	Blue	Blue	White	White	White
Diamondback moth	Blue	Blue	Blue	White	White	White	White	White	White
Bertha armyworm	Yellow	Green	Green	White	White	White	White	White	White
Cabbage seedpod weevil	Yellow	Green	Green	White	White	White	White	White	White
Pea aphid	White	White	White	Blue	Blue	Blue	White	White	White
Pea leaf weevil	White	White	White	Blue	Blue	Yellow	White	White	White
Wheat midge	White	White	White	White	White	White	Green	Red	Green
Wireworms**	Blue	Red	Blue	Blue	Red	Blue	Blue	Red	Blue
Wheat stem sawfly	White	White	White	White	White	White	Blue	Red	Blue
Grasshoppers	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Cereal thrips (primarily in barley)	White	White	White	White	White	White	Green	Yellow	Green

	Legend
Red	Very likely contribute to damage in the following year's crop
Yellow	Somewhat likely contribute to damage in the following year's crop
Blue	Negligible effect on following year
Green	Likely decrease in pressure
White	Unknown effect or not applicable

*Alfalfa seeded in the fall are at higher risk of damage the following spring.
**Planting into established grasses can contribute to damage.

Effects of Crop Rotation on Soil Moisture Availability and Nutrient Supplies

The most influential factors for crop production in Saskatchewan are soil moisture and soil nutrients. They are often the determining factors for crop rotation. Conversely, crop sequencing impacts soil water availability and soil nutrient supply.

Therefore, growers can use crop rotation to manage and improve water and nutrient use efficiencies.

In the semi-arid regions of Saskatchewan, crop production depends highly on available water in the root zone. Crop rotation must consider spring soil moisture conditions and anticipated rainfall during growing season. The precipitation in growing season impacts crop yields more than spring soil moisture reserve. This led to the development of the Growing Season Climate Index Zones (NFRZ) that formed the basis of modified soil testing recommendations based on water use efficiency (Table 3).

However, spring moisture conditions can be improved by conservation techniques while the precipitation cannot be changed unless you have irrigation capability.

Spring soil moisture reserves can be improved by: 1) managing snow distribution in the field; and 2) preventing soil moisture loss from drying winds and excessive runoff. Saskatchewan farmers leave a stubble on the field to trap snow in winter and reduce surface runoff and evaporation in spring.

Generally, stubble six to nine inches tall can conserve half to one inch more water over winter compared to a field that was cultivated in the fall.

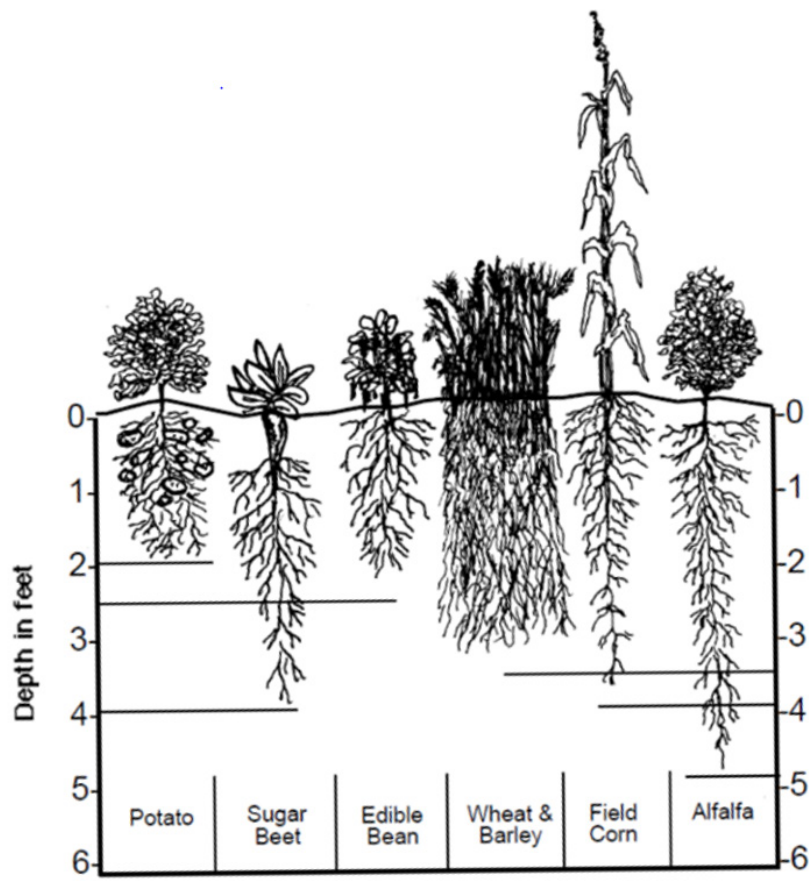
Table 3. Average Moisture use Efficiency For Major Crops in Saskatchewan and Prairies in General.

NFRZ Zone	Wheat	Barley	Oats	Canola	Flax	Peas	Alfalfa	Brome
	bu/inch					cwt/inch		
Palliser Dry Plain (Dry Brown)	4.2	6.3	7.2	2.7	2.1	3.6	8.2	3.7
Palliser Plain (Brown and Dark Brown)	4.8	7.2	8.4	3.0	2.4	3.9	10.6	4.8
Parkland (Black)	5.1	8.1	9.6	3.6	3.0	4.8	12.0	5.7
Moist Parkland (Thin and Thick Black)	5.4	8.7	10.8	4.2	3.6	5.4	13.3	7.2
Humic Parkland (Red River Valley)	5.7	9.0	12.0	4.5	3.9	6.0	13.3	7.8
Alberta Highlands	5.7	8.7	12.0	4.2	3.6	5.4	12.0	7.8
Dry Peace Country	5.1	7.8	9.6	3.8	3.3	4.8	12.6	7.2
Peace Country	5.4	8.4	10.2	3.8	3.3	4.8	13.3	7.5
Moist Peace Country	5.7	8.7	10.8	4.1	3.3	5.4	8.2	7.8

1 Karamanos et al., 2001. Nitrogen Fertilizer Recommendation Zones. p 546-550, Proc. Soils and Crops 2001, February 22-23, University of Saskatchewan, Saskatoon, Sask.

This additional one-inch of water can result in 2.4 to 9.1 bu./ac. more yield depending on crop variety and the soil climate zone (Table 1).
Furthermore, with zero-till and direct seeding, the stubble remains standing after the new crop is sown, soil moisture loss is further reduced in early growing season, which is crucial for crop germination and early development. **Crop rooting depth affects soil water availability and water use efficiency. Deep-rooting crops often access soil moisture at lower horizons while the shallow-rooting crops only use the available water in the upper layer. Generally, alfalfa, safflower and sunflower roots are deeper than barley, canola, oriental mustard and wheat, which have roots that are deeper than field pea, flax and lentil. For each crop, rooting depth is influenced by several factors such as soil moisture depth, precipitation amount and frequency, nutrient availability and soil temperature.**

Figure. 1 Unrestricted effective rooting depth of selected mature crops.



Growers can optimize crop water use by rotating between deep- and shallow-rooted crops (Fig. 1). Shallow-rooted crops appear better to follow deep-rooted crops because water recharge is likely to occur near soil surface and a shallow-rooted crop will use this moisture very efficiently. Medium or deep rooted crops following shallow-rooted crops can take advantage of any moisture left at depth that wasn't used in the previous shallow-rooted crop to start and develop deep roots to access soil moisture at lower layers.

Some crops are more sensitive to soil moisture than others. Agriculture and Agri-Food Canada's (AAFC) studies at Swift Current and Assiniboia have shown that sunflower and safflower yields are almost same on fallow and on stubble.

Field pea and lentil on stubble can achieve about 80 to 90 per cent of the yields on fallow. In contrast, wheat yields on stubble were only 2/3 to 3/4 of that on fallow. Mustard yields on stubble was were less than 2/3. Safflower or sunflower are excellent selections for stubble seeding, while wheat and mustard should be grown on fallow.

Most Saskatchewan growers usually focus on crop needs of nitrogen (N), phosphorus (P), sulphur (S) and occasionally potassium (K). In some soils, micronutrient availability can be extremely low and directly affect crop production.

Growing a pulse crop can reduce the need for N fertilizer. Pulses obtain their N from the atmosphere through a process called biological N-fixation.

N-fixation can provide 50 to 90 per cent of pulse crop total N requirement, which is a significant saving in fertilizer purchase. Additionally, crops following pulses also require less N fertilizer. The pulse residue contains high amounts of N in the chaff, straw and root material. The residue breaks down quickly returning N to the soil where it becomes available to the following crops. Pulse crops also contribute to succeeding crops by increasing productivity with crop rotation benefits such as development of Arbuscular Mycorrhizal fungi (AMF) which helps crops access nutrients from the soil. For example, AAFC's study in Swift Current has indicated that pea crops affect the structure of the AMF community associated with the roots of the following wheat crop, resulting in increased crop yield.

Complementary cropping practices also help improve nutrient use among different crops. This is where different crops have different needs for, or sensitivity to the deficiency of particular nutrient elements. One of the benefits of crop rotation between deep-rooted and shallow-rooted crops is that the deep-rooted crops scavenge the nutrients, in particular the micronutrients, from lower horizons to meet their growth need. These exist in the crop residues, return to the soil and become available for the following crops. Another practice is to rotate between high-and low-nutrient demand crops in order to slow the process of nutrient deficiency.

For example, when soil copper levels are marginal, a wheat–pea–oat–flax rotation is preferred over a wheat–canola–barley–flax rotation, because pea and flax have a low sensitivity to low levels of copper (Rigas Karamanos).

Table 4. Crop Characteristics With Regards to Soil Water Use.

Length of active growing season is the best overall guide to the relative amount of soil water depletion. Rooting depth is also an indicator of depletion.

	WATER DEPLETION	SEASON LENGTH	ROOTING DEPTH
SUNFLOWER	heavy	long	deep
CORN	heavy	long	mod. deep
SOYBEAN*	mod. heavy	mod. long	mod. shallow
SP. WHEAT	medium to mod. Light	mod. short	medium
CANOLA	mod. heavy to mod.light	medium but variable	medium
DRY PEA	light	short	mod. shallow

* Soybean was grown in the Phase II crop sequence experiment.

NDSU

Source: Diversifying Cropping Systems Enhances Productivity, Stability and Nitrogen Use Efficiency.

Table 5. Annual N Fertilizeer Applied (kg N ha^{-1}) at Swift Current, Saskatchewan, Canada from 2004 to 2015.

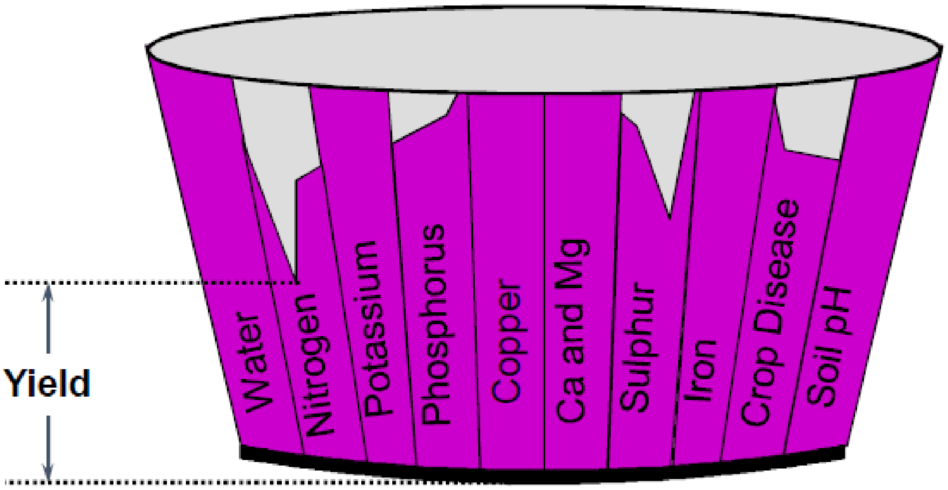
	Rotation[a]					
Year	F-W-W	GM-W-W	F-W-W-W	ContW	W-C-W-P	Mean
2004	28	22	34	48	43	35
2005	25	17	35	54	42	35
2006	33	19	36	56	45	38
2007	23	11	25	7	27	25
2008	25	13	34	48	42	32
2009	32	13	37	40	35	32
2010	23	12	24	33	26	24
2011	38	27	42	54	36	40
2012	28	23	36	57	41	37
2013	27	25	31	48	44	35
2014	34	22	40	59	46	40

Source: Diversifying cropping systems enhances productivity, stability and nitrogen use efficiency.

Core Ideas from study at Swift Current Agriculture and Agri-Food Canada Office.

- Long-term studies reliably assess stability and resource use efficiency.
- Diversified crop rotations produce more than cereal or fallow systems.
- NUE is higher in continuous than fallow systems.
- Green manure systems are highly vulnerable in semiarid environments.
- Fallow systems are more stable but less productive than continuous cropping systems.

Figure. 2 Liebig's "Law of the Minimum"



Adapted from AIA conference; R. Karamanos

Liebig's "Law of the Minimum" states that plant growth will be restricted if one of the essential plant nutrients is deficient even if all other nutrients are abundant. This law is extremely important when considering micronutrients. If a soil is deficient in any of the micronutrients there will not be a positive yield response from further applications of N-P-K-S fertilizer products. However, the interactions between nutrients, e.g., nitrogen and sulphur, phosphorus and zinc, copper and manganese can defy this law.

A nutrient is available to the plant when it is accessible to plant roots. Remember this for when looking at soil testing. Nutrient availability encompasses; the chemical and physical status of a nutrient in the soil and plant root relationships which involve plant metabolism.

According to Rigas Karamanos, nutrient availability depends on the nutrient concentration of the soil solution at any given time. Availability largely depends on the soils physical and chemical ability to absorb and hold soil nutrients and is governed by two factors. First the quantity factor which represents the amount of available nutrients otherwise known as the labile pool. The second is the intensity factor which reflects the strength of retention by which the nutrient is held in the soil, in simpler terms it is the concentration of the nutrient in the soil solution.

Available Nutrients

- Macronutrients such as N, P, K and S and all micronutrients are only deemed available if they are readily accessible by the roots, this is important to remember when analyzing soil test results.
- The chemical and physical characteristics of the soil affect nutrient availability.

Conditions Affecting Macronutrients (N, P, K, S):

- Parent material
- Soil texture (fine clay textured soils retain more nutrients)
- Soils with over 30 per cent organic matter (potassium)
- Poor soil drainage (gaseous losses for N and S)
- Soil temperature
- Poor soil aeration
- Poor Cation Exchange Capacity (CEC) in the soil
- Cool, moisture saturated soils
- High levels of other macros will affect the availability of others

Conditions Affecting Micronutrients:

- Low organic matter (Boron, Copper, Zinc)
- Sandy Soils (Chloride, Copper, Zinc, Boron, Molybdenum)
- Soils with over 30 per cent organic matter (Copper, Boron, Manganese)
- Cool, wet soils reduce the ability of plants to uptake nutrients
- High soil pH (Copper, Zinc, Iron, Boron, Manganese)
- Soils with high concentrations of lime (Zinc and Iron)
- Soils suffering from extreme erosion (Zinc)
- Soils with excessive levels of Phosphorus (Zinc)

According to Rigas Karamanos, nutrients are supplied to the roots through root interception and contact exchange, mass flow and diffusion. Root interception and contact exchange is achieved through the root and root hair penetration of the soil. Roots produce H+ ions, which they exchange with cations from the soil solution. Interception occurs through the root surface being in contact with soil colloids. In general, considered a minor contribution to plant uptake.

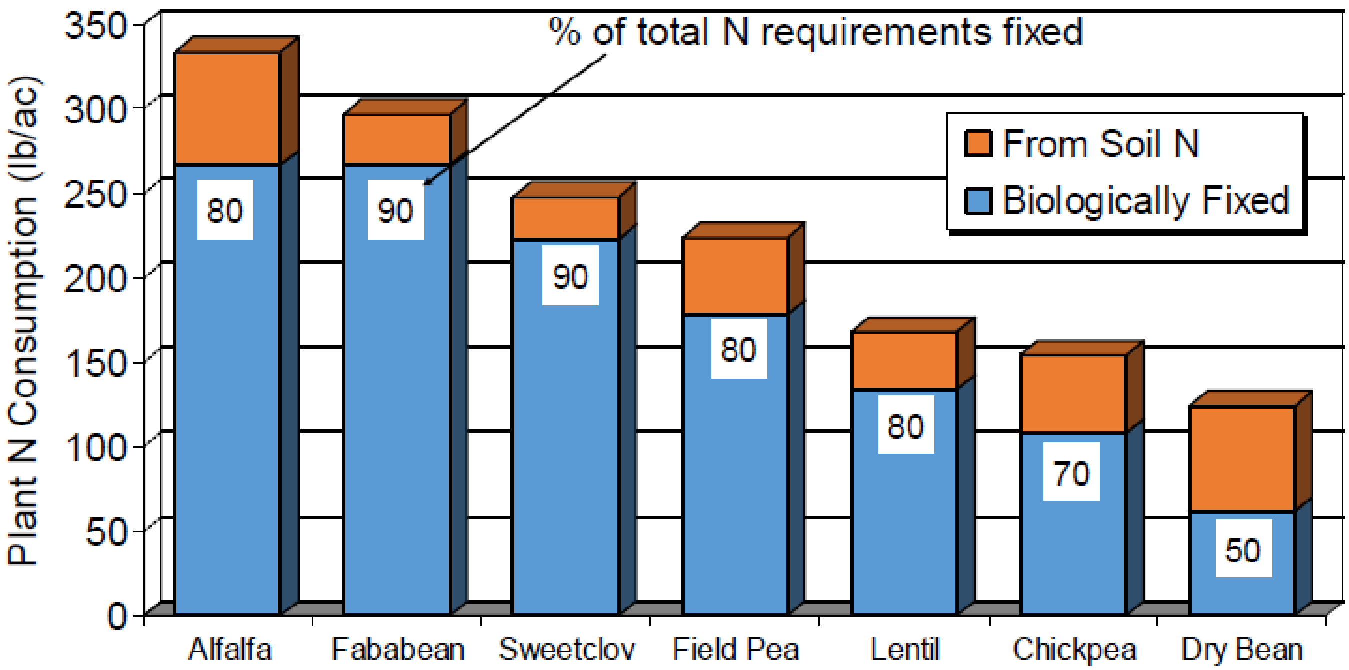
Diffusion occurs when an ion is transported from a higher to a lower concentration by random thermal motion. It occurs in response to concentration gradients between the zone immediately surrounding the root and the soil zones further away.

Regarding mass flow, solutes are transported with the convective flow of water from the soil to plant roots. The amount of nutrients reaching the root depends on; the rate of water flow or the water consumption of the plant and the average nutrient concentration of the water. The level of particular nutrient around the root may be increased, decreased or remain the same depending on the balance between the rate of its supply to the roots by mass flow and the rate of uptake by the root.

Nitrogen Fixation

- Biological - activity of soil bacteria
- Natural Oxidation - lightning (three - 10 lb. N/ac/yr)
- Air pollution - zero - five NH_4/ac/yr, zero - six NO_3/ac/yr
- Industrial- the most important process, synthesizes ammonia using hydrogen from natural gas and atmospheric nitrogen.

Figure. 3 N Fixation Amount Varies With Crop.



Adapted from AIA conference; R Karamanos

Nutrient uptake by field crops inadvertently means that a portion of the nutrient will be removed in the harvested part(s) of the crop. For crops that are grown for their seed, this portion is limited to the seed, whereas for those grown for hay it extends to the whole plant. Different nutrients have different mobility within plaants, so they will also tend to acumulate in diffrent plant parts.

Guidelines for Nutrient use in Saskatchewan Crops

Table 6. Nitrogen Taken Up By Various Saskatchewan Crops.

Crop	Yield bu./ac.	Grain lbs. N/ac.	Straw lbs. N/ac.	Total Uptake lbs. N/ac.	Total Uptake lbs. N/bu.
Spring Wheat	40	54 - 66	22 - 27	76 - 93	1.9 – 2.3
Winter Wheat	50	47 - 57	14 - 17	61 - 74	1.2 – 1.5
Barley	80	70 - 85	30 - 37	100 - 122	1.3 – 1.5
Oats	100	55 - 68	41 - 49	96 - 117	1.0 – 1.2
Corn	100	87 -107	51 - 61	138 - 168	1.4 – 1.7
Canola	35	61 - 74	39 - 49	100 - 123	2.9 – 3.5
Flax	24	46 - 56	18 - 22	64 - 78	2.7 – 3.3
Sunflower	50	48 - 59	19 - 23	67 - 82	1.3 – 1.6
Lentils*	30	55 - 67	27 - 34	82 - 101	2.7 – 3.4
Peas*	50	105 - 129	33 - 39	138 - 168	2.8 – 3.4
Fababeans*	50	154 – 188	103 -157	257 - 314	5.1 – 6.3
Soybeans*	30	112 - 120	26 - 54	138 -174	4.6 – 5.8
Alfalfa* hay	2.5 tons			131 - 160	52.2 – 63.8 lbs. N/ ton
Grass hay	1.5 tons			46 - 56	30.7 – 37.7 lbs. N/ton

*Pulse and legume crops are inoculated with specific strains to fix nitrogen.
Source: Nutrient Uptake and Removal by Field Crops – Western Canada; Canadian Fertilizer Institute.

Table 7. P uptake (lb. P_2O_5/A) by Selected Saskatchewan Crops.

Crop	Yield/A	Grain	Straw	Total	Total Uptake lb. P2O5/bu.
Wheat	40 bu.	21-26	8-9	29-35	0.73-0.88
Barley	60 bu.	30-37	10-12	40-49	0.67-0.82
Canola	35 bu.	33-40	13-17	46-57	1.31-1.63
Flax	24 bu.	14-17	4-5	18-22	0.75-0.92
Pea	50 bu.	31-38	7-8	38-46	0.76-0.92
Lentil	30 bu.	17-20	5-7	22-27	0.73-0.90<
Soybean	30 bu.	21-26	3-4	24-30	0.8-1.0
Alfalfa	2 tons	-	-	25-30	12.5-15 lb. P_2O_5/ton
Corn Silage	5 tons	-	57-70	-	11.4-14 lb. P_2O_5/ton
Faba bean	85 bu.	57-66	3-6	60-72	0.70-0.85

Barley field

Table 8. K_2O* (lb./ac) Taken Up By Various Crops.

Crop	Yield bu./ac.	Grain lb. K_2O/ac.	Straw lb. K_2O/ac.	Total lb. K_2O/ac.	Total Uptake lb. K_2O/bu.
Wheat	40	16-19	49-61	65-80	1.63-2.00
Barley	80	23-28	73-89	96-117	1.20-1.46
Oat	100	17-20	114-140	131-160	1.3-1.6
Corn	100	26-30	91-111	116-141	1.2-1.4
Canola	35	16-20	57-69	73-89	2.10-2.54
Flax	24	13-16	26-32	39-48	1.63-2.00
Pea	50	32-39	91-111	123-150	2.46-3.00
Lentil	30	29-36	40-48	69-84	2.30-2.80
Soybean	30	41-42	31-90	72-132	2.4-4.4
Faba bean	85	60-70	80-120	140-190	1.7-2.4
Grass	1.5	-	-	59-72	39-48 lb. b.K_2O/ton
Alfalfa	2 tons	-	-	108-132	54-66 lb. K_2O/ton

*The K content of fertilizers is expressed in the oxide form as K2O equivalent even though no K2O as such occurs in the fertilizer. The designation is a standard expression of relative K contact. Potash fertilizer (KCl) actually contains 51 per cent K, 47 per cent chloride (cl) and two per cent iron and clays. To convert from K to K2O, multiply 1.2, to convert K2O to kK, multiply by 0.83.

Table 9. Sulphur Uptake By Crops In lb. Sulphur/Ac.

Crop	Yield/Acre	Grain	Straw	Total Uptake	Sulphur Uptake (average)
Spring wheat	40 bu.	4 - 5	4 - 5	8 - 10	0.2 lb./bu.
Barley	80 bu.	6 - 8	6	12 - 14	0.16 lb./bu.
Oat	100 bu	4 - 5	8 - 9	12 - 14	0.13 lb./bu.
Rye	55 bu.	4 - 5	10 - 12	14 - 17	0.28 lb./bu.
Canola	35 bu.	10 - 12	7 - 9	17 - 21	0.54 lb./bu.
Flax	24 bu.	5 - 6	7 - 9	12 - 15	0.56 lb./bu.
Pea	50 bu.	6 - 7	5 - 7	11 - 14	0.25 lb./bu.
Lentil	30 bu.	4 - 5	4 - 5	8 - 10	0.30 lb./bu.
Potato	20 tons	11 - 13	5 - 7	16 - 20	0.9 lb./ton
Alfalfa	5 tons	-	-	27 - 33	6.0 lb./ton
Grass	3 tons	-	-	11 - 14	4.2 lb./ton
Barley silage	4.5 tons	-	-	14 - 21	3.9 lb./ton

Integrated Weed Management and Crop Sequencing

Integrated weed management (IWM) and crop sequencing are integral components of sustainable agriculture from an agronomic, economic and environmental perspective. While crop sequencing is generally listed as a part of IWM, crop sequencing is, in fact, the vehicle that systematically implements components of IWM. Good crop sequences can reduce weed densities at the time of crop emergence, minimizing crop yield losses and can inhibit long-term changes in the weed spectrum towards species that are difficult to control. Varying selection pressure is the ecological principle that accomplishes these goals.

What is Integrated Weed Management?

IWM makes use of a combination of different agronomic practices to manage weeds, so that the reliance on any one weed control technique is reduced. Reducing the reliance on one or two specific weed control techniques means that those techniques will be effective for the future use. The object of integrated weed management is to maintain weed densities at manageable levels while preventing shifts in weed populations to more difficult to control weeds. Losses caused by weeds will be minimized without reducing farm income. Controlling weeds with one or two techniques gives the weeds a chance to adapt to those practices.

For example, the use of herbicides with the same mode of action (belonging to the same herbicide group) year after year has resulted in weeds that are resistant to those herbicides. The continuous production of certain types of crops also gives weeds a chance to adapt (downy brome has increased on fields where winter cereals are frequently grown). Integrated weed management uses a variety of control techniques to keep weeds “off balance”.

Weeds are less able to adapt to a constantly changing system that uses many different control practices, unlike a program that relies on one or two weed control tools.

Shepherds Purse (winter annual)

Types of Integrated Weed Management Practices

There are three main types of agronomic practices that you can use to develop your IWM program:

- Practices that limit the introduction ;and spread of weeds (prevent weed problems before they start);
- Practices that help the crop compete with weeds (help “choke out” weeds); and
- Practices that keep weeds “off balance” (make it difficult for weeds to adapt).

Combining a number of practices from each group will allow you to design an integrated weed management program for your farm.

Give Your Crop the Advantage Over Weeds - Help It Compete

Fertilizer placement affects the crop’s ability to compete with weeds. Placing the fertilizer where the crop has access to it, but the weeds do not, allows the crop to be more competitive with weeds. For example, after banding nitrogen fertilizer for four consecutive years, green foxtail densities were reduced by more than 95 per cent under zero-tillage conditions and that was before any in crop herbicide was applied. Similar trends were observed under conventional tillage conditions.

High Seeding Rates can help give the crop an edge on weeds. Extra plants allow the crop to shade weeds and make it more difficult for them to access nutrients and water. The additional competition may give your herbicide a boost and improve the job that it does. Try to use the maximum recommended seeding rate for each crop you grow.

Narrow Row Spacing (six to eight inches) also allows your crop to be more competitive. There may be situations where wide row spacing’s are necessary (residue clearance in zero tillage systems) and higher seeding rates may offset the effect of going to a wider row spacing.

Shallow Seeding (one inch or less) and **Uniform Seeding** are important for fast crop emergence and good establishment, which allows the crop to be more competitive with weeds (see Table 10).

Assuming the seed has been placed in moist soil, the closer it is to the soil surface, the faster the crop will emerge. Weeds that emerge after the crop cause less yield loss than those that emerge before, which is important when determining if it is necessary to spray.

Leafy Spurge (invasive noxious weed)

Table 10. Seeding Depth Affects Crop Emergence.

Seeding Depth (Wheat)	Days to Emergence	Crop Emergence (per cent)
One inch	1.5 days	90
Two inches	3.5 days	81
Three inches	5.0 days	84

Source: Yantai Gan, PhD thesis, University of Manitoba

Shallow, uniform seeding is important for good crop emergence. Seeding wheat at 1 inch in this case gave the fastest, most even crop emergence. A crop that emerges quickly and establishes well will be more competitive with weeds. High-quality seed (large, plump seed) produces vigorous seedlings that improve crop emergence, establishment and yield (see Table 11). Certified seed is your best source of high-quality seed.

Table 11. High Quality, Certified Seed is Important for Field Sanitation and High Yields.

Crop	Noxious Weed Seeds (per kg)	Seeds (per kg)	Yield (bu./ac.)
Certified Wheat	0	0	41.5
Bin-run Wheat	148	671	39.7
Certified Barley	0	0	70.0
Bin-run barley	600	3350	67.0

Source: Crop Development Centre, University of Saskatchewan

Twelve randomly-selected seed samples were taken from certified and bin-run seed sources to demonstrate the importance of certified seed. This table clearly shows that certified seed is your best source of weed-free seed, which is important for good field sanitation. As well, certified seed is of high quality and produces healthy, vigorous seedlings which are important for weed competition and maximum yield potential.

This is demonstrated by the higher yields achieved with the certified seed sources. How you prepare your seedbed can affect crop and weed growth. Ensuring that the crop seed is placed in an ideal growing environment and the weeds are not, is another way to give your crop the edge. On-row packing leaves the soil in the row firm, but loose in between the rows. Zero-tillage systems leave crop residue in between the rows, which shades the soil and keeps it cool. Fewer weeds germinate under zero-tillage because of the reduction in soil disturbance. For example, green foxtail problems are reduced in zero-till systems because weeds are less able to germinate and grow in the zero-till soil environment.

Certain crop varieties can be more competitive than others. Semi-dwarf wheat varieties are generally less competitive than regular varieties. Taller varieties close their crop canopies more completely than shorter types, which help shade out weeds. This is also true of pea varieties. Research shows that yield losses caused by grassy weeds in tall pea varieties are less than half those suffered by shorter varieties. You may still need to spray the taller varieties, but your weed control will be better because of the added crop competition.

Yield losses are dramatically less in taller pea varieties. The variety you choose can affect how competitive your crop will be.

Keep Weeds "Off Balance" - Don't Let Them Adapt

Crops can be chosen so that seeding date is varied from year to year. Wheat and peas are generally sown as early as possible, while crops like canola are planted later to avoid spring frosts. Seeding early gives the crop a jump on weeds that emerge after the crop, while late-seeding allows for a pre-seed herbicide application or a tillage operation to control early-germinating weeds. Weeds that prefer cooler conditions (wild oats, wild mustard) may be more of a concern in early-sown crops, while weeds that prefer warmer conditions (green foxtail, redroot pigweed) could be more of a problem in crops that are planted late. Wild oats can quickly become a serious problem on early-sown fields that are in continuous wheat production. Changing the seeding date from year to year means that specific types of weeds cannot adapt.

Varying herbicide practices is important for keeping weeds "off balance." Rotating herbicides with different modes of action (from different herbicide groups) will help delay the development of herbicide resistance. Herbicide practices can also be varied by taking advantage of the different application windows during the year. Post-emergent herbicides can be applied pre-seeding, in-crop, pre-harvest or post-harvest.

In-crop herbicide applications may be the most important in early-sown crops, but in later sown canola, a pre-seeding treatment may be all that is required in certain years. Likewise, pre-harvest applications might fit for crops that are harvested late, while post-harvest herbicide treatments could play a greater role in early-harvested crops (lentils, winter wheat). Crops differ in their competitive ability. Wheat, barley and canola are more competitive than flax or pulse crops.

Winter cereals (fall rye, winter wheat) are more competitive than spring cereals if they have overwintered well. Growing crops with different competitive abilities is an important technique for keeping weeds "off-balance". Varying the life cycle of the crops you grow will help prevent weeds from adapting. Annual weeds do well where annual crops are grown frequently (wild oats in wheat); winter annual weeds adapt on fields where winter annual crops are used (downy brome or flixweed in winter wheat); and, perennial weeds increase where perennial crops are grown (dandelions in alfalfa). Using crops with different life cycles will help prevent weeds with specific life cycles from adapting and establishing.

Economic thresholds can help you decide if it is necessary to spray weeds, allowing you to save money on your herbicide bill. Economic thresholds make use of yield loss equations that help to determine how much yield you stand to lose at a given weed density. By estimating the yield and price for your crop, you can decide if the return on spraying is worthwhile. Skipping a spray operation can also help with weed resistance management. Not spraying in one year means less selection for herbicide-resistant weeds. Skipping a spray operation also gives more flexibility in choosing herbicides with different modes of action, which is important for herbicide rotation. Reduced selection for resistant weeds and better rotation of herbicides mean that weeds are less able to develop resistance to herbicides.

Crop Rotation forms the framework that truly allows you to keep weeds "off balance." Crop rotations that make use of a small number of crops do not allow much flexibility for varying seeding dates, altering herbicide practices or using crops with different competitive abilities or life cycles. Diversified rotations that use many different crops provide more opportunities for varying your weed control practices. Figures 4. and 5. demonstrate how weeds are less able to adapt when rotations with a number of different crops are used.

Prevent Weed Problems Before They Start

The best way to control weeds is by keeping them out of your fields. **Field sanitation** involves practices that prevent weeds from entering or spreading through your fields. The use of **clean seed** (certified seed), **clean equipment** and **tarping grain loads** are examples of good field sanitation techniques.

This will reduce your weed pressure and decrease the introduction of new and/or noxious weeds in your fields (see Table 11).

Controlling weeds in **ditches** and at the **edges of fields** or around **sloughs** is an important practice for limiting the spread of weeds like Canada thistle and scentless chamomile.

Patches of new **invading weeds** or **herbicide-resistant weeds** should be controlled to prevent them from spreading. If small patches are detected after the normal spraying time, they should be mowed or treated with an appropriate herbicide (glyphosate) to prevent seed set.

Removing weeds before they have a chance to set seed is an important form of field sanitation. Collecting weed seeds by pulling **chaff wagons** behind the combine catches many seeds before they fall to the ground. The use of forage crops (perennial or annual) allows you to **cut weeds** before they set seed. Annual grassy weeds (wild oats, green foxtail) are less of a problem after alfalfa, partly because of weed seed removal. Be aware that spreading fresh manure may return weed seeds that are collected in chaff and forage if they are used for livestock feed. **Composting livestock manure** (one year minimum) will reduce the viability of many weed seeds, although certain weeds can survive longer than others in composted manure.

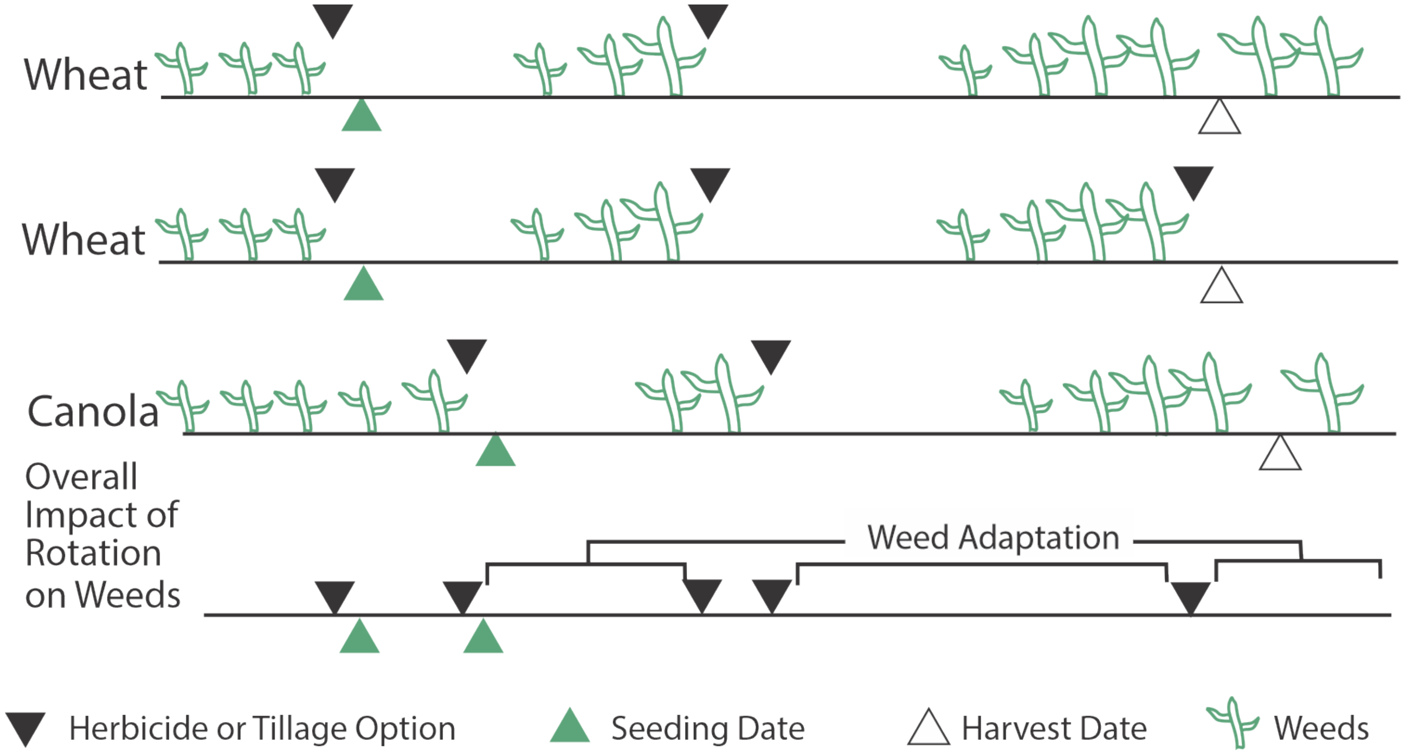
Clover used as cover crop

Integrated Weed Management - Making it Work on Your Farm

There are a number of different practices and techniques that you can use to develop an integrated weed management program for your farm. It's easiest to start by trying a few new techniques (by changing the way, you place your fertilizer, or by growing a crop that you haven't tried before) and then adding more practices as time goes on.

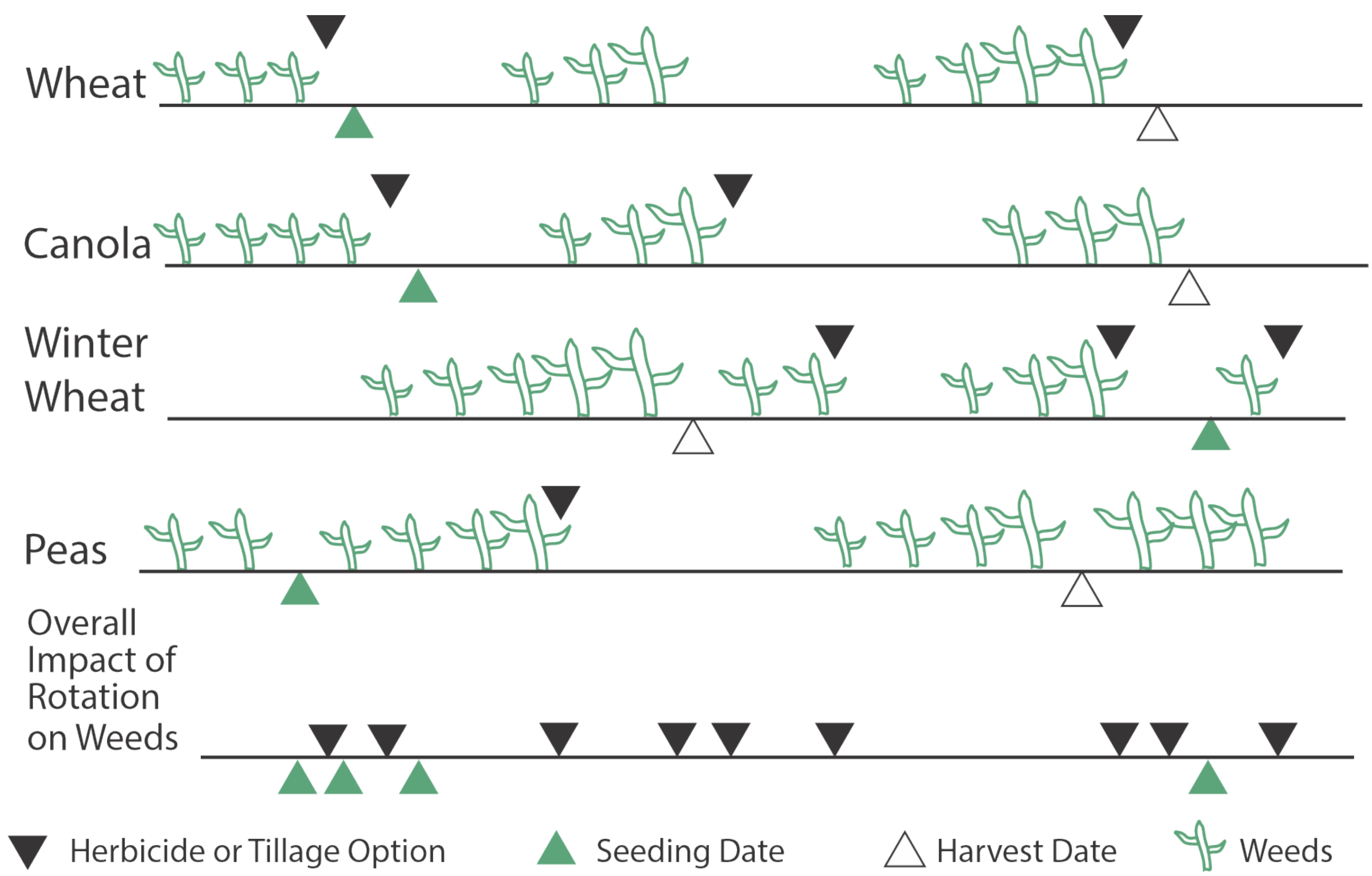
After a few years, you will have developed a system where a number of different management techniques are working together in an integrated control program. The use of a variety of agronomic practices to control weeds reduces the reliance on any one technique or tool, which means that those tools will still be effective for future years. The use of a number of different weed control tools keeps weeds "off-balance" and prevents them from adapting to your integrated weed management strategy.

Figure 4. Non-Diversified Rotations Allow Weeds to Adapt.



The small number of crops in this rotation means there is little variation in seeding dates or herbicide practices and little use of different crop competitive abilities or life cycles. This system gives weeds a chance to adapt.

Figure 5. Diversified Rotations Are Better at Keeping Weeds "Off-Balance."



Diversified rotations that use a number of different crops allow you to manage weeds at many different times over the growing season. The overall effect of the various practices at different times keeps weeds "off-balance."

Your Management Journal

Here's an example of what your weed management journal might look like as you begin to develop an integrated weed management program:

- **April 15 -** Picked up the last of the seed today. Going to try a new variety of peas. It's taller than the other varieties I've tried, so it will hopefully choke out the weeds a little better.
- **May 3 -** Decided to try knifing in the nitrogen as anhydrous instead of broadcasting granular fertilizer. The green foxtail seems to do better where I've broadcasted - banding should give the crop a bit more of a boost.
- **May 15 -** Seeded the last of the wheat. The air seeder seems to be doing a good job. The soil in- between the rows is loose, which should make it tough for weeds to germinate.
- **June 18 -** Decided not to spray the canola for grasses this year. It was the last crop in the ground and not many weeds came after seeding. Did some rough weed counts and the numbers just didn't seem to justify spraying.
- **July 15 -** Saw some chamomile showing up down by the slough. I think I'll mow it out before it sets seed. Also saw an odd-looking patch of wild oats - might spray it with Roundup if it looks resistant.
- **August 8 -** Going to apply pre-harvest Roundup this year on some of the wheat. Want to clean up the thistle a bit since it may go into lentils next year.
- **August 25 -** The new truck tarps don't take much time to roll out and I don't have to worry as much about spilling grain - or weed seeds!
- **September 10 -** Just finished seeding the winter wheat. It should help clean up some of the wild oats and green foxtail on that field. Will check later for winter annual weeds.
- **October 15 -** Sprayed a couple of pea fields for stinkweed and shepherd's purse today. Less residue from the peas should let me direct-seed those fields next year. Winter annuals seem tougher to kill after they bolt - should do a better job by spraying this fall.

Fertilizer for Tame Forage

If a forage stand has been hayed for several years without additional fertilizer, deficiencies are likely. How you fertilize the stand depends on if it is pure grass or pure legume or a mixture of grass and legume.

Grass has a relatively high demand for nutrients. Generally, for each ton of dry matter harvested, about 25 to 30 lb./ac. of N, 10 lb./ac of P2O5, 50 lb./ac. of K2O and five lb./ac of S are taken up from the soil. For each ton of alfalfa removed, about 60 lbs./ac of N (mostly from N-fixation), 14 lbs./ac. of P2O5, 60 lbs./ac. of K2O and six lbs./ac of S are taken up from the soil. Removal rates vary depending on grass and alfalfa types (species, age, etc.) and growing conditions.

Research on a grass stand in north-east Saskatchewan during the 1980s showed that growing season fertilizer containing some of the four major nutrients provided a significantly better response to yield over a 10-year period compared to blends that contained one or two major nutrients. This demonstrated the need for a soil test as the basis for a balanced nutrient blend that meets the specific needs of pure and mixed stands of grass and alfalfa.

If a stand is predominantly grass with little to no alfalfa, it may be best to wait until early spring to fertilize because most cool-season grasses are adapted to take advantage of spring soil moisture and temperatures. Take this time to soil sample in late-fall, assess fertilizer requirements and pricing and determine feasibility.

Early-spring application of urea will provide a rapid response, cool temperatures will reduce the risk of volatilization and urea is likely the most cost-effective form of N fertilizer. As a rule of thumb, the following responses can be expected per pound of N applied: Brown soil zone = 10 – 15 lbs. forage; Dark brown soil zone = 15 -25 lbs. forage; Black and Grey Wooded soil zones = 20 – 30 lbs. forage. Response will vary greatly depending on moisture and several other factors. These figures are provided as a means for rough calculation of feasibility based on N fertilizer cost.

If a decision is made to fertilize a grass stand early in the fall, it is best to use an urease inhibitor or wait until November to reduce the risk of N volatilization. Polymer coated fertilizers are not recommended.

In mixed stands with less than 50 per cent alfalfa the amount of N recommended by soil test is reduced by the percentage of alfalfa left in the stand. For example, if the recommended amount of N fertilizer for a pure grass stand is 65 lb./ac., then the recommended N in a stand with 25 per cent alfalfa would be reduced by 25 per cent to 40 lb. N/ac. But here again, since the grass is the dominant plant type, it may be better to wait until spring.

If a stand has greater than 50 per cent alfalfa, it will not benefit from added N and the emphasis on fertility should be placed on other nutrient needs of the alfalfa. In most cases, P is the most limiting nutrient. Since alfalfa root development continues in the fall, nutrient uptake will occur until the soil freezes, thus a fall application is beneficial. Phosphorus and potassium are of particular importance as they contribute to root and nodule health and over-wintering resilience. Both nutrients can be fall broadcast on stands that are not subject to runoff.

Table 12. General N Fertilizer Recommendations for Grass for Each Soil Zone.

Soil Test N	Soil Zones					
(lbs./ac in 0 -24 in.)	Irrigated	Brown	Dark Brown	Thin Black	Black	Dark Gray and Gray Wooded
*N (lbs./ac)						
0-10	200	70	80	100	120	110
11-20	190	60	70	90	110	100
21-30	180	50	60	80	100	90
31-40	170	40	50	70	90	80
41-50	160	30	40	60	80	70
51-60	150	20	30	50	70	60
61-70	140	10	20	40	60	50
71-80	130	10	10	30	50	40
81-90	120	-	-	20	40	30
91-100	110	-	-	10	30	20
101-110	100	-	-	-	20	10
111-120	90	-	-	-	10	-

* Rates of N lbs./ac assume good moisture conditions and average growing season precipitation. Adapted by R. McKenzie from Alberta Agdex 541-1.

Table 13. Phosphate Fertilizer Recommendations for Grass in Alberta (Modified Kelowna Soil P Test).

Soil Test P	Soil Zones					
(lbs./ac in 0 - 6 in.)	Irrigated	Brown	Dark Brown	Thin Black	Black	Dark Gray and Gray Wooded
P2O5 (lbs./ac)						
0-10	60	35	40	45	50	45
10-20	50	25	30	35	40	35
20-30	45	15	20	25	30	25
30-40	40	10	10	15	20	15
40-50	35	10	10	10	10	10
50-60	30	10	10	10	10	10
60-70	25	10	10	10	10	10
70-80	20	10	10	10	10	10
>80	0	0	0	0	0	0

Adapted by R. McKenzie from Alberta Agdex 541-1.

Table 14. Potash Fertilizer for Irrigated Grass in Alberta (Ammonium Acetate Extraction).

Soil test K lbs./ac 0-6 in.	K2O recommendation (lbs./ac)
0-25	160
25-50	145
50-75	125
75-100	110
100-125	90
125-150	75
150-175	55
175-200	40
200-225	20
>225	0

Adapted by R. McKenzie from Alberta Agdex 541-1.

Table 15. Sulphur Fertilizer Recommendations for Grass (Calcium Chloride Extraction).

Soil Test SO4 lbs./ac 0-12 in.	Sulphur recommendation (lbs./ac)
0-5	20
5-10	15
10-15	10
15-20	5
>25	0

Adapted by R. McKenzie from Alberta Agdex 541-1.

Although it is best to soil test to determine exact nutrient requirements, alfalfa can generally benefit from 40-50 lbs. of phosphate broadcast on pure or mixed stands in the fall. Alternatively, P can be dribble banded or applied using a spoke injector. This annual maintenance application will not only increase the productivity, it will also help the alfalfa persist. K is generally not deficient in Saskatchewan soils but can be limiting on sandy soils. Sulphur is also important for alfalfa growth and can be deficient. A soil test is generally required to determine if a stand will benefit from including P, K and S in a fall application.

In considering future plans for forage fertility, the tables above from Alberta's Ministry of Agriculture and Forestry provides a good set of general guidelines. Although the tables are geared towards spring application for pure grass stands, they can be used together with the information above to plan a balanced fall application on stands dominated by alfalfa or a spring application on stands that are predominantly grasses.

Spring N amounts for stands with less than 50 per cent alfalfa will need to be adjusted as described above. P, K and S removal amounts are similar enough between alfalfa and grass that the tables for these can be used for both pure grass and alfalfa or mixtures with greater than 50 per cent alfalfa. If you are unsure about how to apply soil test information, you may wish to consult with an agrologist.

Forage in Rotations

Integrating perennial forages into annual crop rotations can reduce N fertilizer costs, improve soil health, improve yields, reduce herbicide-resistant weeds and interrupt pest and disease cycles. Forage legumes fix nitrogen from the atmosphere. Nitrogen fixation potential within a stand is affected by moisture conditions, the amount of legume present and the species and the quality of the stand. Following stand termination, the nitrogen release rate to the following crop depends on the total amount of nitrogen within the plants at the time of termination, the level of organic matter, microbial activity within the soil and moisture and temperature conditions.

Long-term residual yield studies of forages in cropping systems reported additional yield benefits lasting several years after breaking. In general, grain yields are enhanced when legume or legume/grass mixtures are included in rotations in the Black and Gray soil zones but tend to cause yield reductions in the drier Brown and Dark Brown zones. Yield response to forage in rotation is mainly due to nutrient or moisture differences but the rotation itself can also create synergies between crops which can enhance yield. Rotation benefits tend to be greatest in areas with higher moisture.

Forage in rotation also contributes to soil health. There is an increasing recognition that living root systems of perennial forages most closely mirror native prairie ecosystems resulting in more biologically-active soils. Adding perennials to a rotation extends the period for living plants to release exudates from roots which helps proliferate mycorrhizal fungi and other symbiotic organisms in the soil. A short growing season marked by periods of hot dry weather in the Prairie region underscores the importance of perennials in enhancing this process.

In addition to enhancing microbial biomass, forage crops also help store soil carbon. Increasing soil organic carbon improves soil tilth, reduces erosion risk by increasing aggregation and improves water infiltration and moisture holding capacity.

With rise of herbicide resistance, perennial forages in rotation are a good practice for addressing herbicide-resistant weeds. Weed suppression by perennial forages in rotation is well documented. Although stands tend to have higher dandelion and shepherd's purse populations, good control of wild oat, green foxtail and Canada thistle has been observed for up to three years after forage crops.

Summary

Crop rotation affects and is affected by, water and nutrient use, disease, weeds and seeding systems. Producers are encouraged to use the information contained in this bulletin and from other sources to continually re-determine the 'best' crop rotation (sequence) for each field according to problems, circumstances and commodity prices.

Also, rotating herbicides and maintaining accurate herbicide use records are critical in planning crop rotations. For more information, contact Agriculture Knowledge Centre at 1-866-457-377.

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