Irrigated Crop Production Update 2006 Conference

January 17, 2006

Lethbridge Lodge Hotel
Lethbridge, Alberta

Organized by:

- **Alberta Agriculture, Food and Rural Development**
- **Southern Applied Research Association**

Organizing Committee:

Ross McKenzie, AAFRD
Roger Hohm, AAFRD
Rob Dunn, AAFRD
George Lubberts, Complete Agronomic Services
Keith Mills, Agricore United
Leigh Morrison, AAFRD
Robert Spencer, AAFRD
Elizabeth Tokariuk, Southern Applied Research Association
Don Wentz, Reduced Tillage Linkages
Judy Lee, AAFRD
Bev McIlroy, AAFRD

AGENDA

Tuesday, January 17, 2006

8:00 REGISTRATION

9:00 OPENING COMMENTS – Brent Paterson, Head, Irrigation Branch

IRRIGATION CROPPING PRACTICES – George Lubberts, Chairman

9:10 Jack Payne, Olds College – Understanding crop growth dynamics
9:30 Dr. Frank Larney, AAFC – Lessons from long-term irrigated crop rotation research
9:50 Rob Dunn, AAFRD – Seeding practices for irrigated cereals and canola

10:10 COFFEE BREAK

IRRIGATED CROP NUTRIENT MANAGEMENT – Leigh Morrison, Chairman

10:30 Dr. Ross McKenzie, AAFRD – Soil fertility and crop nutrition – A balanced approach!
11:00 Dr. Tom Jensen, Agricore United – Nitrogen fertilizer, forms and methods of application
11:20 Dr. Rigas Karamanos, Westco – Micronutrients for irrigated production
11:35 Dr. Barry Olson, AAFRD – Understanding how to use manure or compost to optimize irrigated crop production!
11:50 Trevor Wallace, AAFRD – Logistics for manure handling

12:05 LUNCH

PEST MANAGEMENT UNDER IRRIGATION – Keith Mills, Chairman

1:00 Scott Meers, AAFRD – Insect thresholds for irrigated crops
1:20 Dr. Jim Moyer, AAFC – Re-cropping practices after residual herbicide use
1:40 Dr. Ron Howard, AAFRD – Field crop disease review and forecast
2:00 Dr. Kelly Turkington, AAFC – Irrigation and plant disease management

2:20 COFFEE BREAK

IRRIGATION CROP WATER MANAGEMENT – Gregg Dill, Chairman

2:40 Ted Harms, AAFRD – The R.A.T. of irrigation management: The future for improving irrigation efficiencies
3:00 Dr. Shelley Woods, AAFRD – Irrigating to enhance quality and yield
3:20 Dr. Allan Walburger, U of L – Irrigation economics – What is an inch of water worth?
3:40 Roger Hohm, AAFRD – New irrigated crops of the future

4:00 CONFERENCE WRAP UP – Ross McKenzie and Roger Hohm, AAFRD

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Understanding crop growth dynamics

Jack Payne
Olds College, Olds, AB

Paper not available.

Lessons from long-term irrigated crop rotation research

F.J. Larney[1], N.Z. Lupwayi[2], R.E. Blackshaw[1], J.J. Nitschelm[3], H.A. Carcamo[1], H.H. Mündel[1], H.C. Huang[1], D.C. Pearson[1], D.D. Reynolds[1] and G.H. Dill[4]

Introduction

Irrigated cropping offers a dual challenge of producing high value crops while maintaining soil quality. Common irrigated crops (e.g. potatoes, beans, sugar beets) produce little crop residue for return to the soil and tight rotations may have long-term detrimental effects on our soil resource in terms of diminished soil quality and increased erosion risk.

An rrigated rotation study was initiated in 2000 to examine the impact of conventional and sustainable rotations for potatoes, sugar beets, beans, soft wheat and timothy. The merits of each of six rotations are judged using data on crop yield and quality, weed, insect, and disease pressures and soil quality.

Our objectives are to devise crop sequences and tillage management systems for irrigated land that: (1) optimize crop response; (2) reduce soil erosion, enhance soil quality and promote long-term sustainability; and (3) minimize weed, insect and disease pressures.

Experimental Treatments

The following crop rotations were established in spring 2000 at Vauxhall, AB. The 2005 growing season represented the 6th crop year of this study.

	Rotation	Management
1 Yr	W	Cont. wheat (baseline)
3 Yr	(P-B-W)c	Conventional
3 Yr	(P-B-W)s	Sustainable
4 Yr	(W-SB-B-P)c	Conventional
4 Yr	(W-SB-B-P)s	Sustainable
5 Yr	P-W-SB-W-B	Sustainable (cereal break)
6 Yr	O(t)-T-T-SB-B-P	Sustainable (forage-based)

W = wheat; P = potatoes; B = beans; SB = sugar beet; O(t) = oats harvested as green feed in July, timothy seeded in late August, T = timothy.

Each phase of each rotation was represented resulting in 26 treatments. These were replicated four times to give 104 plots. The plot dimensions were 10 x 18.3 m with a 2.1 m interplot area between each plot.

[1] Agriculture and Agri-Food Canada, Lethbridge, AB
[2] Agriculture and Agri-Food Canada, Beaverlodge, AB
[3] Rogers Sugar Ltd., Taber, AB
[4] Alberta Agriculture, Food and Rural Development, Lethbridge, AB

The sustainable rotations are built around four specific management practices:
(1) direct seeding or reduced tillage where possible
(2) fall-seeded cover crops where possible
(3) composted cattle manure as a substitute for inorganic fertilizer
(4) straight cutting of solid seeded rather than undercutting of wide-row seeded beans

Results

Table 1 shows that in 2005, the 3 yr conventional rotation with wide row beans (1319 kg ha^{-1}) produced lower yields than the narrow row beans in the 3 yr sustainable rotation (2941 kg ha^{-1}). Also in the 4 yr rotation the conventional treatment (1726 kg ha^{-1}) was significantly lower-yielding than the sustainable rotation (2890 kg ha^{-1}). Averaging all 6 years, the longest 6-yr rotation (narrow row) produced the highest yields (2306 kg ha^{-1}), while the 5 yr rotation (narrow row beans direct seeded into shredded wheat stubble, 1888 kg ha^{-1}) and the conventional 3-yr rotation (wide row, 1906 kg ha^{-1}) yielded lowest.

Table 1. Rotation effect on bean yields (kg ha^{-1}) at Vauxhall, 2000-05.

Year	Rotation					
	W-P-B		P-W-SB-B		P-W-SB-W-B	P-O-T-T-SB-B
	Conv.	Sust.	Conv.	Sust	Sust.	Sust.
2000	1939ab†	2157a	2139a	2117a	1695b	2040a
2001	2834ab	2140bc	3116a	2343abc	1772c	2043bc
2002	1149bc	926c	1540ab	1525ab	1109bc	1705a
2003	2407a	2108a	2109a	2054a	2760a	2180a
2004	1788a	2094a	2198a	2449a	2070a	2355a
2005	1319b	2941a	1726b	2890a	1919b	3515a
6-yr avg	1906	2061	2138	2230	1888	2306

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

For potatoes (Table 2), there was no significant effect of rotation on yield in the first five years of the study. Therefore on the compost-amended plots, fertilizer inputs of P could be cut back to zero and N by one third and yields were not significantly different that the rotations receiving all their nutrients from fertilizer. However in the 6th year (2005), the 4-yr sustainable rotation (43.9 Mg ha^{-1}) yielded significantly higher than both the 3-yr conventional (28.6 Mg ha^{-1}) and sustainable (32.7 Mg ha^{-1}) rotations. Averaging all six years, the overall lowest rotation was the 3-yr conventional one which was about 10% lower yielding (37.7 Mg ha^{-1}) than the average of the other five rotations (41.9 Mg ha^{-1}).

Wheat yields (Table 3) were highest overall on the 3-yr sustainable rotation for 2001, 2002 and 2003. The continuous wheat (Cont. W) was the significantly lower in all years except the initial one (2000). In 2005, the wheat following sugar beet in the 5-yr rotation was significantly higher yielding (5.63 Mg ha^{-1}) than all other treatments except the 3-yr conventional treatment (4.53 Mg ha^{-1}). Over the 6-year period, continuous wheat yielded about 70% of the average yield of the other rotation treatments.

Table 2. Rotation effect on potato yields (Mg ha^{-1}) at Vauxhall, 2000-05.

Year	Rotation					
	W-P-B		P-W-SB-B		P-W-SB-W-B	P-O-T-T-SB-B
	Conv.	Sust.	Conv.	Sust	Sust.	Sust.
2000	36.6a†	39.8a	39.3a	38.0a	33.1a	37.9a
2001	42.1a	48.1a	54.2a	45.8a	51.3a	50.1a
2002	27.2a	33.1a	29.1a	22.8a	30.7a	26.2a
2003	46.2a	51.8a	47.5a	50.0a	48.6a	49.7a
2004	45.5a	49.5a	43.7a	45.5a	51.5a	49.7a
2005	28.6d	32.7cd	37.8abc	43.9a	35.4abcd	41.1ab
6-yr avg.	37.7	42.5	41.9	41.0	41.8	42.5

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

Table 3. Rotation effect on wheat yields (Mg ha^{-1}) at Vauxhall, 2000-05.

Year	Rotation						
	Cont. W	W-P-B		P-W-SB-B		P-W-SB-W-B	P-W-SB-W-B
		Conv.	Sust.	Conv.	Sust	Sust.	Sust.
2000	4.76ab†	5.14ab	4.35b	4.78ab	4.39b	4.66ab	5.33a
2001	5.42b	8.50a	8.77a	8.34a	8.20a	8.23a	8.43a
2002	2.51b	3.37ab	3.97a	3.90a	3.91a	3.11ab	3.59a
2003	2.30b	5.30a	5.51a	4.95a	4.62a	4.17a	3.79ab
2004	5.25b	7.10a	6.67a	6.87a	6.96a	7.22a	6.7a70a
2005	2.64c	4.53ab	4.04bc	3.77bc	3.26bc	3.38bc	5.63a
6-yr avg.	3.81	5.66	5.55	5.44	5.22	5.13	5.58

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

Rotation treatment had no significant effect (*P* = 0.05) on extractable sugar yield in the first 5 years of the study (Table 4). However, in 2004, there was a trend (*P* = 0.13) of higher extractable sugar yield in the 5-yr sustainable rotation (12,637 kg ha^{-1}) than in the 4-yr conventional rotation (11,181 kg ha^{-1}). The 2005 beet yield data analysis has not been completed at the time of writing.

Table 4. Rotation effect on extractable sugar yields (kg ha^{-1}) at Vauxhall, 2000-04.

Year	Rotation			
	P-W-SB-B		P-W-SB-W-B	P-O-T-T-SB-B
	Conv.	Sust	Sust.	Sust.
2000	8267a†	8734a	8739a	8400a
2001	10280a	10848a	10861a	10255a
2002	5864a	6348a	5967a	6247a
2003	9783a	9708a	9918a	10161a
2004	11181a	11952a	12637a	11858a
2005	Not available at time of writing			
5-yr avg	9075	9518	9624	9384

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

Soil Microbial Properties

Each July, beginning in 2002, soil samples were taken from the wheat phase of each rotation for measurement of soil microbial biomass carbon and soil bacterial diversity. Wheat plants were excavated from six random 0.5-m lengths of row from each plot. Loose soil was shaken off the roots, and the soil that adhered strongly to the roots was carefully brushed and kept as 'rhizosphere' soil. Non-rhizosphere ('bulk soil' (0-7.5 cm depth) was sampled from the middle of two adjacent wheat rows near each of the six locations per plot.

Table 5. Rotation effect on soil microbial biomass C (mg kg^{-1} soil), 2002-05.

Year	Rotation						
	Cont. W.	W-P-B		P-W-SB-B		P-W-SB-W-B	P-O-T-T-SB-B
		Conv.	Sust.	Conv.	Sust.	Sust.	Sust.
				Bulk soil			
2002	152b†	134b	159b	121b	156b	155b	297a
2003	386a	425a	526a	369a	429a	402a	464a
2004	703a	505a	559a	485a	650a	485a	561a
2005	519ab	316c	503ab	355c	437bc	582a	542ab
Avg	440a	345bc	437a	332c	418ab	406abc	466a
				Rhizosphere			
2002	248b	274b	260b	226b	305b	264b	406a
2003	485a	413a	489a	493a	372a	453a	407a
2004	501a	424a	492a	514a	501a	537a	579a
2005	475a	373a	395a	363a	482a	520a	520a
Avg	427a	371a	409a	399a	415a	444a	478a

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

Table 6. Rotation effect on soil bacterial diversity (Shannon index, H'), 2002-05.

Year	Rotation						
	Cont. W.	W-P-B		P-W-SB-B		P-W-SB-W-B	P-O-T-T-SB-B
		Conv.	Sust.	Conv.	Sust.	Sust.	Sust.
				Bulk soil			
2002	2.44a†	2.33a	2.56a	2.11a	2.33a	2.58a	2.45a
2003	2.20a	2.10a	2.61a	2.22a	2.34a	2.42a	2.20a
2004	2.68a	2.61a	2.63a	2.60a	2.64a	2.56a	2.50a
2005	1.86a	1.95a	2.58a	1.96a	2.05a	2.42a	1.44a
Avg	2.30bc	2.25bc	2.59a	2.22c	2.34abc	2.50ab	2.15c
				Rhizosphere			
2002	2.52a	2.70a	2.59a	2.68a	2.76a	2.68a	2.81a
2003	2.53a	2.47a	2.56a	2.61a	2.80a	2.64a	2.60a
2004	2.58a	2.61a	2.73a	2.38a	2.52a	2.41a	2.55a
2005	2.42a	2.41a	2.44a	2.24a	2.20a	2.15a	1.99a
Avg	2.51a	2.55a	2.58a	2.48a	2.58a	2.47a	2.49a

†Within rows, means followed by the same letter are not significantly different from each other according to LSD = 0.05.

Microbial biomass carbon (C) is an estimate of both the size of the total microbial community and the mass of potential plant nutrients contained within the cells of the microorganisms. In the bulk soil, the 3-yr and 4-yr sustainable rotations had significantly more microbial biomass C than their conventional counterparts (Table 5). There was also evidence that the longest 6-yr rotation had the highest level of microbial biomass C. The high level of microbial C in continuous wheat indicates that total organic inputs into the soil are also an important factor. For rhizosphere soil, the rotational effect on microbial biomass C was non-significant (Table 5).

The metabolic diversity of soil bacteria, which was analysed by assessing carbon substrate utilization patterns (community-level physiological profiles), is characterized by the Shannon index (Table 6). A higher Shannon index denotes a more diverse or complex soil ecosystem in terms of microbial functions, which makes it generally more stable and more resistant to stress. For bulk soil, even though effects were non-significant for individual years, the cumulative effect, as evidenced by the overall average value, showed that the 3-yr sustainable rotation had significantly higher diversity than its conventional counterpart (Table 6). The 5-yr sustainable rotation had a significantly higher Shannon index (2.50) than the 4-yr conventional rotation (2.22). For rhizosphere soil, as with microbial biomass C, the rotational effect on microbial diversity was non-significant (Table 6).

Other Measurements

Other parameters measured include weed density and diversity, disease pressure (e.g. *Sclerotinia* on beans); beneficial vs. non-beneficial insects, soil fertility and quality properties.

Summary

A trend of better performance in the sustainable vs. conventional rotational practices is starting to emerge in crop yield patterns and soil microbial properties as the study progresses. We need long-term rotation studies to fully understand the interactions that occur when crop choice and sequence are varied. Since the longest rotation is 6 years, the study needs to run for 12 years in order to complete two full cycles and gather meaningful results. It is hoped to continue this experiment up to and including the 2011 field season.

Acknowledgements

We thank the Alberta Agricultural Research Institute, Alberta Pulse Growers, Potato Growers of Alberta, Rogers Sugar Ltd. and Agriculture and Agri-Food Canada's Matching Investment Initiative for funding contributions. Andrew Olson, Paul DeMaere, Mandy Collins, Andrea Eastman and Jim Sukeroff provided technical and field help.

Seeding practices for irrigated cereals and canola

Rob Dunn, Conservation Cropping Specialist, AAFRD, Lethbridge, AB
Dr. Ross McKenzie, Research Scientist, AAFRD, Lethbridge, AB

This presentation will focus on seeding rates and dates for cereals and canola, leaving information on other crops like peas, beans, corn, flax, sugar beets, potatoes and forages to seed suppliers, industry agronomists or contracting companies. To date, irrigated crop agronomic research has been limited, but a new project by AAFRD will investigate best management practices for several irrigated cereal and oilseed crops over the next few years.

Best seeding practices also relate to selection of appropriate field preparation practices and planter design (row spacing, seed delivery system, ground opener and packer). Rapid, uniform emergence is achieved when seed is placed into a firm, moist, warm seedbed at the desired depth – easier said than done in most field conditions! In the interest of time, we'll also save discussion on this topic for another day.

Optimum Planting Dates

Most farmers and agronomists recognize the advantage of the earliest feasible planting dates for increased crop yield potential. Typically, there is a gradual yield decline followed by a more rapid decline when seeding is further delayed, depending on crop type and variety. The main reasons for the decline are the shortened vegetation and grain filling period, as well as lower water use efficiencies.

Other important factors affecting planting date choice include the following:

- field preparation or planting equipment limitations
- impact on crop quality (eg. protein content or seed size)
- harvest management issues
- riskiness of spring frost
- riskiness of later harvest
- timing for availability of irrigation water

Crop species differ in their ability to tolerate cool, early spring soil temperatures and post emergent frosts. In general, cereals are most tolerant because the growing point remains below ground. Peas are one of the exceptions amongst broadleaf crops with good frost tolerance, able to re-grow from a scale node at or near the soil surface following severe frost damage. For oilseeds, mustard species tend to have more frost tolerance than canola but neither will survive a severe frost.

Ross McKenzie, research scientist with AAFRD at Lethbridge looked at the impacts on yield and quality for three planting dates with several crops including malt barley, soft wheat, mustard and winter wheat. Trends were similar for both dryland and irrigation with the earliest dates (mid April to early May) almost always yielding as high or higher than the mid date and the third date having the lowest yield.

Irrigated malting barley was evaluated at 2 locations with reduced yields for later planting dates. For example, irrigated yields declined by 7% and 23% for the second and third dates at Lethbridge in 2001. Grain protein tended to be higher for later planting dates while the effect on kernel plumpness was inconsistent.

Research on irrigated soft wheat at 3 sites in 2004 showed no difference between first and second planting dates but an 8% yield reduction for the third date. There was a more pronounced effect in 2005 with a 6% and 18% yield reduction for the second and third planting dates. Bushel weight tended to increase with later planting in 2004 but was unaffected in 2005.

Optimum Seeding Rates

Cereal crops, canola and mustard have the ability to compensate for low plant populations and therefore, achieving the correct plant population is not so critical as crops like corn, beans, and sugar beets. For this reason, less attention is paid to seeding rates compared with other agronomic factors like weed or fertilizer management. However, the process of compensation delays development, allowing space for weeds and consequently, reduces yield potential compared to a uniform, densely populated crop stand.

Some of the many factors affecting seeding rate are as follows:

- relative seed size
- germination and anticipated survival
- species ability to compensate for low populations
- relative seed cost versus potential benefits
- herbicide options (eg. herbicide tolerant versus conventional canola)
- intended market (eg. barley forage versus feed versus malt)

It is important to distinguish between seeding rate and target plant density, which is the estimated population after allowing for germination and seedling mortality losses. Survival can vary dramatically between species, seed lots or field conditions. Cereals typically range from 70 to 85% and canola from 30 to 70%. In general, as seeding rates increase, percent survival is less but overall plant populations are still higher. For this reason, it is more difficult (and expensive) to reach very high plant populations.

Still another consideration is the impact of seeding rates on weed control and disease risk. Higher plant populations will tend to reduce weed density and help to augment herbicide performance on target weed species. Leaf, stem, head or pod related diseases may be accentuated because of increased crop canopy humidity with higher plant populations.

Results from the first two years of an irrigated soft wheat study by Ross McKenzie at Lethbridge suggest the optimum target density is 250 m^{-2} plants. In earlier studies, this was the optimum target for yield and quality of irrigated malt barley with feed barley at 300 plants m^{-2}. Silage studies from 1999 to 2001 suggested the optimum plant density for barley at 300 m^{-2} and spring triticale at 350 m^{-2}.

Brian Beres, research agronomist with AAFC looked at seeding rate effects on yield, weed and disease related issues for several winter wheat varieties on irrigation at Lethbridge. Increasing the rate from 300 to 450 seeds m^{-2} increased weed suppression and leaf disease severity with no effect on yield. Actual plant populations the following spring were 200 and 290 plants m^{-2} for the 300 and 450 m^{-2} seeding rates (65% survival).

Recommended irrigation seeding rates are summarized in Table 1 for several cereal types and canola based on southern Alberta trial results and information supplied by the Canola Council of Canada. The table uses average values for seed survival and shows a range of seed sizes. The formulae for calculating seeding rates based on actual seed size and target populations is available on Ropin' the Web at the following:
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81

The range of numbers shown in Table 1 illustrates the importance of checking the relative seed size before determining a seeding rate. For example, most farmers plant canola at 5 lb/acre despite the fact that seed sizes can vary by as much as 30 to 40%.

Table 1. Recommended target density and seeding rate for irrigated cereals and canola.

	Target density (plants m^{-2})	Seed size range (grams/1000)	Anticipated survival (% of seeds)	Seeding rate (kg/ha)
Soft wheat	250	34 - 41	85	109 - 131
CWRS wheat[z]	250	35 - 42	85	112 - 135
Durum wheat[z]	250	43 - 45	85	138 - 144
Winter wheat	250	32 - 37	75	116 - 134
Malt barley	250	38 - 50	85	122 - 160
Feed/forage barley	300	35 - 49	85	146 - 188
Triticale forage	350	43 - 45	85	177 - 185
HT Canola[y]	80	3 - 5	50	5 - 9

[z]Southern Alberta research to determine optimum seeding rates begins in 2006.
[y]Based on information from Canola Council of Canada.
(Conversions: Plants m^{-2} *.91 = plants ft^{-2} kg/ha * .88 = lb/ac)

References

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Soil fertility and crop nutrition – A balanced approach!

Ross H. McKenzie
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Irrigated crops require a number of different nutrients. There are at least 16 elements known to be essential for plant growth. Carbon (C), hydrogen (H), and oxygen (O) are derived from carbon dioxide (CO_2) and water (H_2O). Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) are normally derived from the soil in the form of inorganic salts. Ninety-four to 99.5 per cent of fresh plant material is made up of carbon, hydrogen and oxygen. The other nutrients make up the remaining 0.5 to 6.0 per cent. Macronutrients refer to those elements that are used in relatively large amounts, whereas micronutrients refer to those elements that are required in relatively small amounts (Table 1).

Table 1. Essential plant nutrients.

Supplied from air and water	Supplied from soil and/or fertilizer sources	
	Macronutrients	Micronutrients
Carbon (C)	Nitrogen (N)	Zinc (Z)
Hydrogen (H)	Phosphorous (P)	Copper (Cu)
Oxygen (O)	Potassium (K)	Iron (Fe)
	Sulphur (S)	Manganese (Mn)
	Calcium (Ca)	Boron (B)
	Magnesium (Mg)	Chlorine (Cl)
		Molybdenum (Mo)
		Cobalt (Co)

Nitrogen (N) is often the most deficient of all the plant nutrients. Most crops are very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. This paper will focus on soil N cycling and factors affecting N fertilizer utilization.

NITROGEN

The utilization of applied nitrogen fertilizer depends on the availability of soil nitrogen and the potential losses of applied nitrogen. Various other agronomic factors can cause a poor response to applied nitrogen including:

Cultivar
Varieties with higher yielding potential will respond to higher rates of applied nitrogen than those with lower yield potential, providing that other factors are not limiting.

Available Soil Nitrogen
Available soil nitrogen at planting time is one of the main factors that will influence crop response to fertilizer nitrogen. The nitrogen status of a field can be estimated from the previous cropping history, but is more accurately determined by a soil test. Soils that have low plant available nitrogen will require more fertilizer nitrogen.

Delayed or Late Seeding
Late seeding usually results in a lower yield potential and therefore reduced response from nitrogen fertilizer due to moisture/heat relationships. Also, there is greater risk of crop loss from increased disease pressure, insects, frost and poor harvest conditions.

Weed Competition
Weeds compete with crops for moisture, nutrients and light. Applied nitrogen fertilizer may stimulate the growth of weed seedlings almost to the same extent as crops. It is therefore important to control weeds in order to minimize the competition between weeds and wheat plants. Banding fertilizer or placing fertilizer with the seed makes it less accessible to weeds during the early growing season. However, if too much fertilizer is seed-placed, injury to the seedling will reduce emergence resulting in higher weed competition.

Disease Infestation
Well nourished, healthy plants provide a measure of resistance to many disease organisms. Inadequately nurtured plants seem to be predisposed to certain diseases such as common root. Some diseases are reduced such as take-all root rot when cereal crops absorb ammonium nitrogen and is increased when the plants take up excessive amounts of nitrate nitrogen.

Soil Moisture and Irrigation
Spring soil moisture reserves and level of irrigation management must be considered when choosing fertilizer rates.

Understanding Nitrogen Losses

It is very important to understand how nitrogen can be added or lost from the soil. There are a number of terms used to define N additions and losses.

Volatilization: Nitrogen from fertilizers containing ammonia or urea can be lost through volatilization as ammonia gas to the atmosphere. Ammonia volatilization increases with increasing soil pH, soil carbonate content and pH of the added fertilizer. These types of losses are greatest with urea (46-0-0) followed by liquid N fertilizer (28-0-0), which is half urea. Losses are greater when soil temperature is >5° C and air temperature is > 10° C.

Losses are greater in alkaline (high pH) soils than from acid soils and are higher under dry as compared to wet surface soil moisture conditions.

The losses from sandy soils are usually higher than from heavier textured soils and are greater at high temperatures than at low temperatures. Greatest volatile losses can occur where there is just enough moisture to put fertilizer into solution, but not enough to move it in to the soil, followed by hot, dry windy conditions. Loss due to ammonia volatilization can be eliminated or greatly reduced if fertilizer is banded or well incorporated into the soil.

Ammonium fixation: The ammonium (NH_4^+) form of nitrogen can be temporarily retained by some clay minerals. Much of this nitrogen can be used by the plants at some time during the growing season. Ammonium fixation is generally not considered to be a major factor by which fertilizer nitrogen availability is reduced.

Erosion: Nitrogen fertilizer can be lost in runoff waters and through soil erosion caused by either wind or water. Runoff losses of applied fertilizers can be reduced by banding fertilizer into the soil. Cultural methods to control wind and water erosion should be used to minimize N losses. Generally, it is not advisable to apply fertilizer to frozen soils.

Leaching: Leaching refers to the movement of nitrate nitrogen in the soil solution through and out of the root zone. When leaching occurs, nitrate nitrogen is lost from the root zone, as a result of downward movement of excess water through the root zone. Nitrate leaching can occur from early spring to late fall under excess, moisture. It is generally most severe on sandy soils. Generally, nitrate leaching is a less serious concern in clay soils. Leaching losses of nitrogen applied in the spring close to the time of seeding are minimal on most soils. Leaching losses are also reduced by using ammonium fertilizers banded into the soil.

Immobilization: Immobilization refers to the conversion of plant available nitrogen to organic nitrogen by soil micro-organisms. This nitrogen is not lost but is tied up temporarily and is released slowly for crop use through mineralization. It is important to remember that soil microbes compete with growing crops for applied nitrogen fertilizer, which may result in reduced crop growth.

Immobilization of ammonium nitrogen is slightly greater than immobilization of nitrate-nitrogen. Considerable amounts of inorganic nitrogen are removed by immobilization (20 to 40%) from the available form. Higher nitrogen immobilization in surface soil under minimum and zero till management may reduce available nitrogen to crops in the early part of the growing season. Banding of nitrogen rather than broadcast incorporation is effective to decrease nitrogen losses by immobilization.

Denitrification: This process results in the reduction of nitrate-nitrogen to nitrogenous gases such as nitrogen (N_2) and nitrous oxide, which are lost to the atmosphere. Considerable nitrate-nitrogen may be lost by denitrification when soils are temporarily wet (early spring or after heavy rainfall). This occurs when soils are saturated for extended periods. Microorganisms obtain oxygen from nitrate by converting nitrate to nitrogenous gases.

For this reason, nitrogen fertilizer should not be applied in the fall to areas that are subject to saturated soil conditions in the spring or to low lying land subject to flooding. Because of possible denitrification losses, it is generally recommended that fall applied nitrogen be banded in the ammonium form and applied as late as possible when the soil is cold, so that the nitrogen will remain in the ammonium form. Denitrification losses do not occur as long as the fertilizer nitrogen is present in the ammonium form.

Nitrogen Fertilizer Application in Fall Versus Spring

Farmers frequently ask about the relative effectiveness of fall versus spring nitrogen fertilizer applications. In a nutshell, fall fertilization can range from very effective to disastrous depending on soil moisture, the form of nitrogen used and how it is applied. To understand why we must understand the fate of fertilizer N in soil. Fertilizer N is applied to soil in the form of urea ($CO(NH_2)_2$), anhydrous ammonia (NH_3), ammonium (NH_4^+), or nitrate (NO_3^-) depending on the product used. Urea and anhydrous ammonia quickly convert to ammonium. It is the ammonium and nitrate forms that are taken up by plants. If the soil is warm, moist and well aerated, ammonium is rapidly oxidized to nitrate through the nitrification process. This is a biological process performed by highly specialized soil bacteria.

Banding slows the nitrification process by creating an environment near the band that inhibits the activity of the bacteria converting ammonium to nitrate. Therefore, if urea or anhydrous ammonia is banded in late fall, most of the N is retained in the ammonium form until the soil warms up in the spring. If the fertilizer is broadcast or banded in early fall, likely most of the ammonium will be converted to nitrate prior to freeze-up, large losses can occur when soils are water saturated during and just after snow melt in early spring. The losses are caused by an anaerobic process called denitrification, which converts nitrate to nitrogen and oxygen gases.

Table 2. Efficiency of nitrogen fertilizer application.

Application method	Irrigation in southern Alberta
Spring Broadcast and Incorp	100
Spring Banded	110
Fall Broadcast and Incorp	95
Fall Banded	110

Research has also shown that denitrification will occur in virtually all of our agricultural soils. This is not surprising since denitrification is not a particularly specialized function. Many different types of soil bacteria use denitrification as an alternative form of respiration when oxygen is in short supply.

What this means in terms of fertilizer management is that no soil type or region of the province is 100% safe when it comes to losses of fall-applied N. In general, however, N losses through denitrification in southern Alberta are normally small and fall banded N is equal to spring banded N (Table 2). In cases where spring banding causes a significant loss of seedbed moisture, fall banding can be superior to spring banding. Typcially, denitrification is greatest on irrigated soils after extended saturating rain conditions in spring and summer.

Also keep in mind that denitrifying bacteria are less than 2 millonths of a metre in size. They could care less about the regional climate or moisture level. They only respond to what is happening in their tiny corner of your field. What does this mean? It means micro-climate is also important. Even during dry springs, there are localized wet areas such as depressions where denitrification can occur. Think about this in terms of your own fields. Are they uniformly flat and well drained? Not likely. There are always spots that are wetter than the rest. Where runoff accumulates after a rain or spring snow melt. Over winter N losses can vary greatly over a short distance. Fall-applied N can be very effective on upland and totally ineffective in a depression just a short distance away.

It is important to remember fall-application always puts your fertilizer N at risk. The level of risk is generally assessed at the regional level, but whether or not losses occur is a function of very local conditions. General rules about application methods and timing:

- Generally spring banded is the most effective method of application and fall broadcast the least effective.
- Fall banded N will be as effective as spring banded if there is no extended period of saturation in the spring.
- Fall banded N may be more effective than spring banded when lack of seedbed moisture is a concern.

With this information in mind here are a few tips to consider before fertilizing in fall:

- If your soils tend to be saturated with water for extended periods in the spring, then fall-application is probably not a good option. However, if saturated soil conditions are normally not a problem, then you should get good results from fall banding.
- Soil test to determine the optimum rates of fertilizer required. Producers should sample 0-6, 6-12, and 12-24 inches to determine the cumulative N to two feet.

- Select a fertilizer formulation that is right for your conditions. Generally under low risk conditions such as in southern Alberta, anhydrous ammonia (82-0-0), urea (46-0-0) or liquid nitrogen (28-0-0) perform equally well when fall banded. However, soils in southern Alberta tend to be alkaline and losses through ammonia volatilization can occur if the bands are too shallow or the soil is dry and cloddy.
- Avoid the use of the nitrate containing products such as 28-0-0 on soils that tend to be saturated in the spring. Nitrates are subject to both denitrification and leaching losses under wet spring conditions, so N won't convert to nitrate in the fall.
- Apply N in late fall after the soil temperature has dropped below 7° C and the nitrification process has slowed down.
- Band, don't broadcast. Banding restricts the contact between soil and fertilizer and as a result over winter losses are lower.

As you can see there are a number of agronomic factors to consider before fall application of N fertilizer. You may want to consult with a soil fertility specialist while you're setting up your fall fertilizer program. Other management factors should also be considered in deciding to fall fertilize including:

- Fall fertilization can improve your time management. By applying fall-fertilizer a field operation can be eliminated in the spring and allow earlier planting.
- Fertilizer prices and payment schedules tend to be more favorable in the fall, making it economical to fall apply.
- Availability of product and application equipment is often better in the fall than during the peak demand periods in spring.
- Soils tend to be drier in the fall, so N application equipment is less likely to cause soil compaction.

This covers the major points to keep in mind when deciding to fertilize in the fall. It is always a good idea to get several opinions and consider all the factors before you make your final decision.

Nitrogen Fertilizer Placement

The method of placement and time of application can have significant effect on the efficiency of nitrogen fertilizer by increasing yield and/or protein. Methods of application include:

1. Drilling in with the seed
2. Sideband placement
3. Banding into soil prior to seeding
4. Broadcast and incorporated into the soil
5. Broadcast without incorporation
6. Foliar application

A number of factors influence the magnitude of crop response to N fertilizer and its placement. These include:

1. Rate of fertilizer - the higher the rate, the less impact placement will have.
2. Soil test levels - the higher the soil test level, the less impact placement will have.
3. The higher the rainfall, the less impact placement has.
4. Crop rotation - legumes in rotation with cereals can reduce the impact of placement.

<u>Drilled in with the seed:</u> Drilling N with the seed is one of the most effective means of adding nitrogen fertilizer. The safe rates of N fertilizer that can be seed-placed is provided in Table 3. If seedbed moisture conditions are favorable, up to 45 kg N/ha (40 lb/ac) can be applied with the seed of cereal crops. More

than 20 kg N/ha (18 lb/ac) when applied with a double disc drill can cause seedling damage and reduce yield increases. Higher rates of urea can be used with seeding equipment which spread the seed and fertilizer in a wider band. Many air seeders are capable of creating a band 10 to 20 cm (4 to 8 inches) wide.

Sideband placement: Sideband placement of N is equal in effectiveness to N drilled with the seed, however, it has the advantage that higher amounts can be used. Attachments for side banding are only available on some types air seeders and direct seeding equipment. Therefore, this type of N placement has limitations to fertilize spring wheat. A form of side banding which has been developed in recent years is the paired row system, where fertilizer is placed between two seed rows. Certain hoe drills and air seeders can be adapted for this purpose. An advantage of side banding is that fertilizer is more selectively available, favoring the crop more than the weeds.

Table 3. Safe rates of seed-placed fertilizer.

Crop	Soil texture	Seedbed soil moisture	Phosphate	*Double disc or narrow hoe drill		**Pneumatic seeder 50% spread	
				Urea	Ammonium nitrate[z]	Urea	Ammonium nitrate[z]
				lb/ac of Nitrogen (N)			
Wheat Barley Oats	Medium to fine	Good	50	30	45	45	65
		Poor	50	20	30	30	45
	Coarse	Good	50	20	30	35	55
		Poor	50	15	20	25	35
Small seeded crops	All textures	Good	10-20	10	20	20	35
		Poor	0-10	0	10	10	25
Other crops	For safe N rates other crops – consult a crop specialist						

[z] Ammonium nitrate is no longer sold in Canada

Banded into soil prior to seeding: Banding N into soil, prior to seeding is about equal in effectiveness to side banding or seed placement. Nitrogen fertilizer is applied in a band behind a shank or disc at depths of 7.5 to 10 cm (3-4 in). Generally, seeding can take place immediately after fertilizer application. In the past, it was recommended that seeding be delayed for two days after banding anhydrous ammonia (NH_3). However, in many soils as long as the NH_3 is placed 5 to 7.5 cm (2 to 3 in) away from the seed, NH_3 can be applied at the time of seeding. Seed damage from NH_3 is most likely to occur under dry conditions on sandy soils when there is insufficient separation from the seed. Placement of fertilizer nitrogen should be deeper in sandy soils than in loams or heavy textured soils. Narrow band spacing 25 to 30 cm (10-12 in) is better than wider band spacing particularly under low moisture conditions. Research has shown that with low soil moisture, in cool spring conditions, narrower spacing is more effective in minimizing temporary or season long N deficiency.

Broadcast and incorporated into the soil: Generally, this method does not result in a yield and/or protein increases as large as those obtained by band placement. To minimize volatilization losses, urea and liquid or dry fertilizer containing urea should be well incorporated into the soil. Shallow incorporation of these fertilizers may result in ammonia volatilization. In cases where incorporation is not desirable due to moisture or soil conservation reasons, losses are reduced by applying fertilizer at a soil temperature of less than 5°C or by applying ammonium nitrate fertilizer which is not subject to volatilization losses.
Broadcast without incorporation: This method is the least efficient use of fertilizer nitrogen. When urea is

used, ammonia volatilization losses can be appreciable resulting in lower yield and/or protein content than obtained when the fertilizer nitrogen is incorporated or banded. The use of ammonium nitrate is the preferred source of nitrogen for surface broadcast application due to its low volatilization potential.

Foliar nitrogen application: Nitrogen in liquid form has been foliar applied at heading to the soft dough stage with some success to increase wheat protein content. Applications are generally in the range of 7 to 15 kg/ha (6 to 14 lb/ac) of N. Rates above 20 kg/ha can potentially cause some tissue burning resulting in crop injury.

Nitrogen Fertilizer Recommendations

Fertilizer recommendations are based on the results of the soil test analyses and on the nutrient requirement of the crop to be grown. Recommendations on time and method of fertilizer application are also included. Each soil testing lab has its own philosophy for making fertilizer recommendations. Two examples are:

1. Recommendations which indicate the nutrient requirements and yield potentials for optimum economic production based irrigation level, soil N level, N fertilizer cost and estimated crop value. This can be achieved using the AFFIRM computer program available for downing from the Alberta Agriculture web site at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop10159

2. "Target Yield Recommendations" which indicate the nutrient requirements for a range of various lower and higher yield potentials under the same moisture conditions. With this information the producers have the flexibility of selecting a fertilizer application rate or target yield that best suits their individual situation.

PHOSPHORUS

Phosphorus (P) is an important plant macronutrient for irrigated crops, but it is required in smaller amounts than N. Irrigated soils in southern Alberta are not usually severely deficient in soil P as a result of years of P fertilization. Good management of P fertilizer is still very important to optimize irrigated crop production.

Phosphorus Fertilizer Management

The majority of P fertilizer is not absorbed by crops in the year of application. Instead, much of the fertilizer P ends up reacting with soil constituents to form labile, less available P compounds. To maximize P fertilizer uptake and yield response, two management strategies are used: timing and placement.

Timing of P Fertilization

Research in western Canada has also shown that fall and spring banding of P fertilizer are similar in effectiveness.

P Fertilizer Placement

Phosphorus supply during the first 5 weeks of crop growth is critical to achieve optimal yield**.** Therefore, P fertilizer should be placed in a manner that maximizes early season access.

Seed-row placement is an effective placement method when soil P levels are low to moderate and spring soil conditions are cool and wet. Cool wet soil slows the movement of P to roots and the root uptake rate. Cold soil decreases the solubility and diffusion of phosphate in the soil solution. These conditions increase the likelihood of response to readily accessible seed-row P (the "popup" or "starter" effect). Small seeded crops are sensitive to seed-row fertilizer and this limits the amount of seed-row P. The maximum amount of seed-row P fertilizer depends on the crop, the seedbed utilization and soil moisture conditions. Southern Alberta research has shown that seed-placed P with wheat, barley and canola is more effective that banded P about 75% of the time.

Band placement is an effective method since it reduces fertilizer contact with sensitive seed and with soil constituents that will fix P over time. All recommended rates of P fertilizer can be safely banded without risking seedling injury to sensitive crops. Also, the deeper placement of fertilizer tends to be more accessible to roots due to a higher probability of moist soil with depth. Banding fertilizer prior to seeding will reduce the volume of fertilizer needed during seeding, and can provide some time and labor benefits. Band placement is an effective method of placing all fertilizer, not just P. There are several configurations of where the band is placed relative to the seed-row.

Side banding places fertilizer near the seed-row during seeding. The fertilizer normally is banded 1 to 2 inches below and to the side of the seed-row.

Several direct seeding machines use a mid-row or paired-row method of banding fertilizer. P fertilizer can also be banded in late fall or spring prior to seeding. Airseeders with shovels or knives are used with shank spacing ranging from 8 to 14 inches. The fertilizer is usually banded to a depth of 2 to 5 inches, although there generally aren't any agronomic benefits to banding deeper than 3 inches while fuel costs increase significantly with deeper depths. In high P fixing soils, fall P bands should be placed deeper than subsequent tillage depths to avoid mixing the band with soil.

Split application methods refer to combinations of band and seed-row placement. Split application takes advantage of the consistent benefit of seed-placed P fertilizer up to 20 lb P_2O_5 /acre, and avoids seedling injury by placing the remainder of P fertilizer in a band (usually with N).

Broadcast-incorporated placement involves spreading P fertilizer on the surface followed by cultivation to work it into the soil. This is a very common P fertilizer application method on irrigated land but it is the least effective P application method compared to seed-placed or banded P fertilizer due to reduced root efficiency of uptake and increased contact between the P and reactive soil constituents. Application rates with broadcast-incorporated P fertilizer usually have to be 2 to 4 times seed-placed or banded rates to get an equal response. Therefore, broadcast-incorporated methods are usually less economical.

Phosphorus deficiencies on irrigated soils are normally corrected with annual applications of commercial P fertilizer, either mono-ammonium phosphate (12-51-0) for dry blends or ammonium polyphosphate (10-34-0) in liquid blends. Manure also serves as an excellent source of P and other nutrients.

Rock phosphate has been promoted as a viable alternative P fertilizer for crops. Rock phosphate is the relatively insoluble, grey-black powdery material that is refined in fertilizer manufacturing plants into soluble phosphate fertilizer. Research on the prairies indicate that rock phosphates do not perform satisfactorily compared to fertilizer phosphate. The poor performance is due to poor solubility, lower P_2O_5 content.

POTASSIUM

The macronutrient potassium (K) is required in large amounts by irrigated crops, nearly as much as nitrogen. In spite of the large requirement, irrigated crop yield responses to K fertilizer (potash) are infrequent, due to ample soil K reserves and the strong ability of most crops to absorb K. The form of potassium absorbed by plant roots is the cation K^+.

Although crops absorb large amounts of soil K, responses to fertilizer K are rare on irrigated soils in southern Alberta. Past research indicates that most irrigated crops will not consistently or economically respond to fertilizer K unless the soil test is very low (100 to 200 lb K/acre). Very sandy soils are the most likely soil types to have very low K soil test values and respond to K fertilizer. Other factors that increase the likelihood of K deficiency are: free lime in the rooting zone, acid soil, poor drainage, cool temperatures, soil compaction and a shallow root zone.

Potassium Fertilizer Management

Potassium is relatively immobile in the soil since the K^+ cations are readily adsorbed to the negative surface charges on clay particles and organic matter. Potassium can also be fixed into the clay lattice structure of certain clay types. Potassium is more mobile in sandy soil but much less mobile than NO_3^- but somewhat more mobile than phosphate. This relative immobility means that fertilizer placement will greatly affect uptake efficiency. Application methods should minimize contact with soil and increase root contact. Banded and seed-placed methods can achieve good uptake efficiency. Crop responses to K fertilizer in research trials are rare in southern Alberta.

Seed-placed K fertilizer is an efficient application method but the high salt index of potash fertilizer limits the amount that can be safely applied near the seed. Small seeded crops such as canola and most special crops have a much lower tolerance to seed-placed potash than cereals, and stands will be reduced if seed-placed K rates exceed 15 lb K_20/acre with drills that have low seedbed utilization (such as double disc drills). Higher rates of potash fertilizer can be safely seed-placed as the seedbed utilization is increased. If other nutrients such as N or P are also seed-placed, this reduces the safe rate of seed-placed K. Good seedbed moisture, higher clay and organic matter contents help reduce the severity of seedling damage from seed-placed K fertilizer. However, most K deficient soils are sandy, and thus are sensitive to seed-placed K. Due to crop sensitivity to seed-placed K fertilizer, band placement is more advisable. Side band placement is an efficient method and the separation of fertilizer and seed reduces the risk of germination damage. Openers with side band capability are becoming more common, especially for direct seeding implements. Deep banding prior to seeding is also an efficient and safe method of K fertilization. Potash fertilizer can be banded together with other nutrients. Banding efficiency should not differ greatly between fall and spring unless the soil is very sandy and subject to leaching loss under conditions of high snowmelt or spring rainfall.

The broadcast-incorporation application method is less efficient, and probably requires rates double that of banding to achieve a similar crop response, if soil K is deficient. However, in situations where banding equipment is not readily available, and seed placement is too risky, broadcast-incorporation may be useful and not overly expensive due to the relatively low cost of potash fertilizer. The higher rate of K fertilizer broadcast will also benefit subsequent crops that usually have a high response.

SULPHUR

Sulphur (S) is the fourth macronutrient, but ranks as the third most limiting nutrient on the prairies. However, irrigated soils are rarely deficient in S, as irrigation water contains sulphate sulphur. Approximately 30 lb/ac of plant available S is added to soil in 12 inches of irrigation water.

The S form that is taken up by plant roots is sulphate (SO_4^{-2}). Field and greenhouse studies in southern Alberta in the early 1980's by the Lethbridge Research Centre found that barley and rapeseed could utilize SO_4^{-2} from a depth of 24 to 30 inches. Subsoil SO_4^{-2} salt layers are common in Brown and Dark Brown soils across southern Alberta and could affect the yield response to S fertilizer on fields testing low for S in the surface soil.

In most southern Alberta soils, there is a subsoil salt (gypsum) and or lime (calcium carbonate) layer. This subsoil layer contains considerable SO_4^{-2}, often as co-precipitates with lime. Although this subsoil SO_4^{-2} solubility is reduced, it still can contribute to plant needs if it exists within the rooting zone. However, the length of time that crops grow in S deficient topsoil before rooting to the subsoil S will affect the yield response to fertilizer S. Also, the depth to subsoil S tends to vary greatly across the field. Total amounts of S (organic and SO_4^{-2}) generally increase from upper to lower slope positions. In most prairie soils, SO_4^{-2} is not held by organic matter and clay particles since they are both negatively charged. Therefore, SO_4^{-2} is vulnerable to leaching losses particularly on sandy irrigated soils or high precipitation events.

The optimal method and timing of S fertilizer depends on the fertilizer form, sulphate versus elemental forms. Fertilizers based on sulphate are highly soluble and will move easily with water in the soil**.** Ammonium sulphate (21-0-0-24) is a common sulphate based fertilizer. Highest fertilizer use efficiency generally results when sulphate fertilizer is placed near roots for easy access and just before the period of plant uptake. On sandy soils, sulphate leaching can occur during wet periods, and thus fertilizer should be applied just prior to crop needs. Although sulphate fertilization just prior to or at seeding is best, post-seeding applications can be effective followed by an irrigation.

Sulphur fertilizer containing elemental sulphur must be managed differently than sulphate based fertilizer to achieve good efficacy. Elemental sulphur has advantages of ready supply, low production and transportation costs, and fewer drill fills due to high analysis. However, elemental sulphur has a significant disadvantage -- availability is delayed until soil bacteria oxidize it into the SO_4^{-2} form. The rate of this conversion from elemental sulphur to sulphate depends on the particle size, the degree of dispersion in the soil, and the growing conditions for the bacteria (moisture, temperature). Common elemental sulphur fertilizers are formulated as granules or pastilles (split pea shape) for ease of shipping and handling, each consisting of thousands of individual particles. The surface area of these individual particles is the access where the soil bacteria "feed", converting the elemental sulphur to sulphate. Small particles have the largest surface area and therefore the fastest oxidation rate. Under western Canadian conditions, research indicates that particles less than 150 microns in size will convert quickly if well mixed with soil.

Effective use of elemental S fertilizer requires careful consideration of the specific product's particle size, application method and timing, severity of S deficiency, soil leaching risk, and field history of elemental S use. The most consistent response to elemental sulphur fertilizer will be achieved by surface broadcasting the granules, allowing time for granule breakdown by rain/frost/snow, then mixing the particles with soil by tillage. Application of the elemental S fertilizer should be done in early fall.

CALCIUM AND MAGNESIUM

Calcium (Ca) is a macronutrient absorbed in relatively large amounts by crops, approximately comparable to phosphorus and potassium. Of all the macronutrients, magnesium (Mg) is absorbed in the least amount. There are no documented deficiencies of Ca or Mg on irrigated soils in southern Alberta due to ample soil reserves of Ca and Mg. Therefore, Ca and Mg fertilization is not necessary for irrigated production in southern Alberta.

MICRONUTRIENTS

Micronutrients are those nutrients required by plants in extremely small quantities (less than 100 ppm in plant dry weight) which include boron, chlorine, copper, iron, manganese, molybdenum and zinc. These nutrients will be covered in the Karamanos paper.

SUMMARY

Producers must keep in mind that optimum yields of high quality crops cannot be obtained without adequate fertilization, soils are deficient in essential elements. Fertilization, however, will neither increase yield or quality of a crop if other management inputs and cultural practices are not optimal, nor will it increase yield if the added nutrients are not required. Therefore, the most successful fertilizer program will be based on knowledge of soil nutrient status combined with optimum crop and fertilizer management practices.

For further information on optimizing N or other fertilizers contact the Alberta Ag-Info Center at 1-800-882-7677.

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Nitrogen fertilizer, forms and methods of application

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INTRODUCTION

There are at least eleven forms of nitrogen (N) fertilizer that are commercially available around the world (see Table 1) (Western Fertilizer Handbook, 2002). In western Canada we have had access to basically five of these forms, specifically pressurized liquid anhydrous ammonia, granular urea, prilled ammonium nitrate, urea ammonium nitrate solution, and granular ammonium sulphate. (*Note: Ammonium nitrate will be less available as there will be no Western Canadian production for prilled ammonium nitrate after the year 2005 and any product coming into this market will be imported..*) There are often questions whether a grower should use one N-fertilizer form or another. A common statement is that "A Pound Of N, Is A Pound Of N" and if applied appropriately all forms can perform equally well to aid in crop production. The important thing to consider is what does "applied appropriately" mean.

Table 1. Commercially available N fertilizers.

Name	Chemical Formula	Analysis % N-P2O5-K2O
Anhydrous Ammonia*	NH_3	82-0-0
Aqua Ammonia	NH_4OH,	20-0-0
Ammonium Nitrate*	NH_4NO_3	34-0-0
Ammonium Nitrate-Lime	$NH_4NO_3+CaCO_3$	26-0-0
Ammonium Sulphate*	$(NH_4)_2SO_4$	21-0-0-24S
Calcium Nitrate	$5Ca(NO_3)_2\ NH_4NO_3\ 10H_2O$	15.5-0-0-19Ca
Nitrate of Soda	$NaNO_3$	16-0-0
Urea*	$CO(NH_2)_2$	46-0-0
Ammonium Nitrate solution (sol)	$NH_4NO_3 + H_2O$	20-0-0
Urea Ammonium Nitrate (UAN)sol*	$NH_4NO_3 + CO(NH_2)_2 + H_20$	28-0-0/32-0-0
Calcium Ammonium Nitrate (sol)	$5Ca(NO_3)_2\ NH_4NO_3\ 10H_2O + H_2O$	17-0-0-8Ca

* Commonly available in Western Canada.

It can be simply explained as applying the N-fertilizer so that there is adequate mixing with or movement into the soil. Once in the soil the N is either dissolved into soil solution and or adsorbed onto soil particles (clay surfaces or humus material). The ideal goal of adding N-containing fertilizer to a field is to place it where plant roots will contact and absorb it. Once in the plant roots it can be translocated within the plant and used to build plant components such as protein molecules. Each form of N fertilizer has features that can make it more or less subject to losses from the soil-plant system or positionally available to crops. To understand how losses occur it is useful to study the N-cycle.

N-CYCLE

The N-Cycle can be illustrated in different ways, but is often shown as a series of boxes or circles with arrows showing movement from and into the boxes. The boxes represent various components or pools of N that exist in the environment and each pool is made up of N in different molecular forms. The illustration shown below is simplified for the purpose of this discussion.

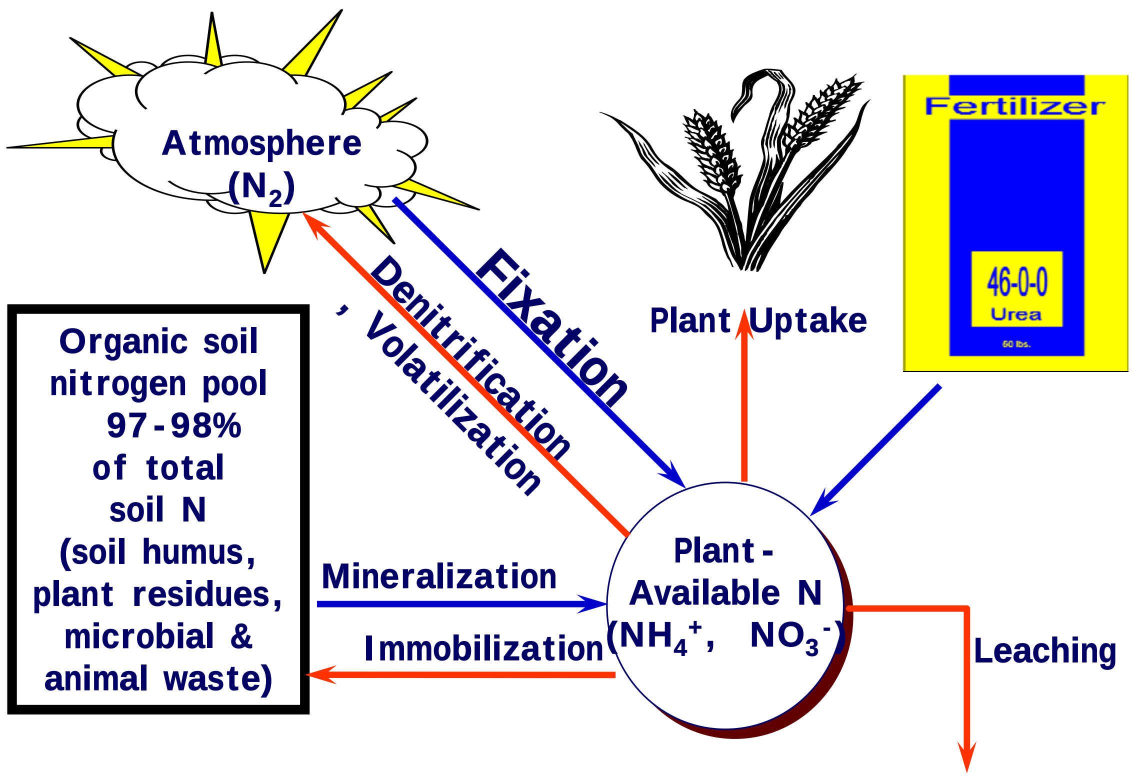

Figure 1. Simplified N-Cycle. (Blaylock, 2000).

The majority of N present in the environment is N_2 gas making up 78% of the atmosphere. The N_2 gas is unavailable to plants unless it is combined with hydrogen and oxygen through a series of chemical or bio-chemical reactions called fixation. Fixation can occur naturally by soil microbes that take N_2 gas and bio-chemically change it over to NH_4^+. Some of these microbes (i,e, *Rhyzobia* species bacteria) accomplish this by symbiotically fixing the N_2 gas using energy from the legume plants on whose roots they live, while other free-living bacteria accomplish this on their own in the soil environment. Chemical N fixation can occur naturally by the strong oxidation reaction of lightning discharge in the atmosphere or industrially in fertilizer plants where hydrogen obtained from methane is combined with N_2 gas and reacts in the presence of a catalyst under intense heat and pressure to form ammonia gas (NH_3). It can be further industrially modified into ammonium, nitrate and urea. Plants primarily take up nitrogen into their root systems in either of the two ionic N forms ammonium (NH_4^+) or nitrate (NO_3^-). There can be some absorption of N through leaves as N_2O, NH_4^+, NO_3^- or urea ($CO(NH_2)_2$) but this absorption by crops is a small amount compared to root uptake. The cation NH_4^+ is relatively immobile in soil and is adsorbed onto negatively charged soil colloids (clays and or organic matter). The anion NO_3^- is quite mobile in soil and moves by mass flow as water moves through the soil. The majority of N uptake by plants in most well-drained soils is in the NO_3^- form resulting from the normal oxidation of NH_4^+ to nitrite (NO_2^-) and further to NO_3^-. This NH_4^+ oxidation is called nitrification and is accomplished by two groups of soil bacteria.

The amount of total N in the soil at any one time is mostly in the organic form (97-98%). It is contained in the organic molecules of soil humus, plant residues, soil fauna, soil microbes or animal wastes. These organic molecules are too large to be absorbed through plant root membranes and need to be decomposed and modified by soil fauna and microbes into the ionic forms NH_4^+ or NO_3^-. This whole decomposition and modification process is called **mineralization**, simply meaning changing organic N forms to mineral N forms. This is not a one-way trip for N as the ionic forms of NH_4^+ and NO_3^- can be returned to an organic form as soil microbes require and use N to decompose high carbon to nitrogen ratio containing plant residues.

The whole N cycle is in a constant state of change and can be described as a type of dynamic equilibrium. Nitrogen fixation from the atmosphere to the soil-plant system is balanced off by a few possible pathways of losses. One is the process of **denitrification** of NO_3^- where NO_3^- is reduced to nitrous oxide (N_2O) or N_2 gases under conditions of low oxygen concentrations in the soil such as water-logged conditions. This is done by soil bacteria that need oxygen to carry out metabolic activities and usually use oxygen gas from the soil atmosphere but can use oxygen from NO_3^- when necessary. Another is **volatilization** losses of NH_3 from the soil surface to the atmosphere by the reduction of NH_4^+ to NH_3 or the hydrolysis of urea or other N-containing organic molecules resulting in free ammonia. Lastly N can also be lost from the soil-plant system through **leaching** of NO_3^- as water moves through and out of the soil into ground water or in some cases surface water.

The goal of N fertilization is to add N-containing fertilizer in a form and place it in a location to minimize losses and maximize plant uptake. It is useful to look at the commonly available N-fertilizers with reference to the N-cycle to help understand how to minimize losses and maximize plant uptake. In summary the losses are **volatilization of NH_3** and **denitrification** and **leaching of NO_3^-**. In the short-term N-fertilizers that are in the NH_4^+ form, or react to form NH_4^+, and have good contact with the soil are not subject to losses. All N-fertilizers will end up primarily as NO_3^- however if given enough time and warmth (soil temperatures greater than 10^oC but less than 30^oC) and adequate but not excessive moisture. A short discussion about each of the five commonly available N-fertilizers follows.

ANHYDROUS AMMONIA (NH_3), 82-0-0

Once liquid NH_3 loses pressure it becomes gaseous NH_3 at atmospheric pressure. If at the soil surface or in the air it is volatile and mixes with other gases in the air. It will react with lower atmosphere compounds and will eventually be deposited to the soil surface. It can however travel short or long distances before being deposited so there is no way to control where it goes once it dissipates into the air.

When NH_3 is injected into the soil an individual NH_3 molecule reacts with a water molecule in the soil to form an ammonium and a hydroxyl ion ($NH_3 + H_2O \rightarrow NH_4^+$ and OH^-). This results in the formation of a zone of a high pH solution of ammonium hydroxide localized around the point of injection. The NH_4^+ ions will at first be adsorbed onto the negatively-charged soil colloids but will begin to spread out slowly due to chemical diffusion. The oxidizing bacteria present in or near the zone of application will cause nitrification of the NH_4^+ to NO_3^-. The mobile NO_3^- ions will then flow with water in the soil and spread out into the soil and be intercepted by crop roots. It does take time for nitrification to occur because it is a microbial process. The nitrifying bacteria need adequate moisture and temperature to function. If NH_3 is applied late in the spring, soil temperatures are cool and soil moisture is limited the spreading out of NO_3^- from the zones of NH_3 injection may be delayed. This is sometimes observed as striping in fields. That is dark-green crops over the zones of injection but in between the zones of injection crop plants may show chlorosis or yellowing due to a mild N deficiency. Usually the chlorosis disappers as the soil warms up, rainfall is received and NO_3^- moves out from the zones of NH_3 injection. Denitrification and leaching losses from NH_3 applications are usually low unless the NH_3 is applied very early during a warm long fall. Nitrification of most of the NH_4^+ may occur and if waterlogged conditions are experienced the following spring denitrification of NO_3^- may be a problem. If NH_3 is applied later in the fall when soil temperartures are reduced below 10^oC or in the spring denitrification losses are normally small.

AMMONIUM NITRATE (NH_4NO_3), 34-0-0

Since half of the nitrogen in this fertilizer form is in the NO_3^- form this portion can be subject to denitrification losses immediately if waterlogged conditions are experienced. It is normally a fertilizer that is applied close to the time period it will be used by the target crop. For example it has been commonly used as a surface broadcast application in the spring for winter wheat and grass seed or grass forage crops. It is not subject to NH_3 volatilization losses unless applied to extremely high pH soils (> 8.5 pH) and the NH_4^+ portion of the fertilizer losses a hydrogen ion (H^+) that reacts with a hydroxyl ion (OH^-) to form H_2O. This doesn't seem to be a problem on most soils in Western Canada as pH levels are normally slightly acidic through neutral to mildly alkaline (6.5 pH to 7.0 pH 7.5 pH respectively). There may be some exceptions on high pH (8.5 pH) soils in the Red River Valley or on eroded knolls where sub-surface carbonates are at the soil surface.

AMMONIUM SULPHATE ($(NH_4)_2SO_4$), 21-0-0-24S

This fertilizer is not subject to denitrification losses in the short-term compared to NH_4NO_3 and is well suited to surface applications due to low or no NH_3 volatilization losses. Its disadvantage is a lower N-analysis resulting in higher transportation costs. It is an excellent S-fertilizer source and when used as the primary N source the value of S may not be recovered especially on soils containing adequate S levels. However with NH_4NO_3 being withdrawn from the Western Canadian market and more $(NH_4)_2SO_4$ becoming available as an environmental-by-product of the energy industry scrubbing S emissions to reduce SO_2 sulphur emissions. It may be used more as a N fertilizer in the future for surface applications. This fertilizer can be mixed in a 50:50 blend with urea to make a 34-0-0-11 fertilizer that is less subject to volatilization losses than straight urea. The 34-0-0-11 fertilizer blend has 69% of the nitrogen in urea form and 31% in ammonium form.

UREA ($CO(NH_2)_2$), 46-0-0

This fertilizer has the highest analysis of N of all granular fertilizers. It is hydrolyzed in the presence of the naturally occurring urease enzymes in the soil or on crop residues to release free ammonia. When left on the surface after broadcast applications there may be some NH_3 volatilization losses. Under cool conditions these volatilization losses are minimal such as if applied in the late fall or early spring. But if applied in the late spring or summer under warm conditions losses can range between 15 to 30 % unless rainfall or irrigation soon follows application. A rainfall of 15 to 20 mm is usually sufficient to dissolve and move the soluble urea into the soil before much hydrolysis occurs. Once in the soil with sufficient water the NH_3 resulting from hydrolysis of the urea molecule becomes NH_4^+ ions and losses are minimized. If incorporated or banded in the soil the free ammonia becomes NH_4^+ following the same mechanism described for NH_3 and volatile losses are minimal. The two NH_4^+ ions resulting from each molecule of urea are changed to NO_3^- through nitrification as is the case for all NH_4^+ based fertilizers. It is also commonly used as a granular source in a fertilizer blend that is broadcast and then incorporated into the soil using tillage. It is less subject to denitrification in the short-term compared to ammonium nitrate and can be a good choice for surface applications in late fall or early spring. Once temperatures warm up N-top-dressing applications may be less subject to losses if ammonium nitrate, ammonium sulphate or urea ammonium nitrate solution is used.

UREA AMMONIUM NITRATE SOLUTION (UAN), 28-0-0

This liquid fertilizer is a mixture of dissolved ammonium nitrate and urea in an approximate 50:50 blend along with enough water to keep it in solution and not precipitate or salt-out. It has loss properties that are characteristically half like urea and half like ammonium nitrate. The urea portion can be subject to NH_3 volatilization losses while the ammonium nitrate portion is not. The NO_3^- portion of the ammonium nitrate can be subject to denitrification losses if waterlogged conditions are experienced soon after application. Surface applications are generally recommended to be surface-dribble-banded because if sprayed evenly over the surface of the soil into a thatch cover much of the fertilizer may adhere to the surface residue and not move readily into the soil beneath the residue (e.g. established forage crop or a no-till seeded crop). If banded into the soil it will perform well compared to banded urea or banded ammonia. There is some mention that this form of N-Fertilizer is more available to plants because it comes pre-dissolved in water. However the amount of water in the fertilizer is miniscule compared to the amount of water present in a soil near normal field capacity. Liquid fertilizer storage, distribution, metering and field application systems do have some convenience advantages over other N-fertilizer forms and is a popular N-fertilizer in some areas.

CONCLUSION

In most cases all of the above discussed N-fertilizers can adequately fill the N-requirements of a crop if applied in a way to minimize losses and maximize crop uptake. Generally the cost per pound of nitrogen is least for ammonia, then in order of increasing cost is urea, UAN, ammonium nitrate and lastly ammonium sulphate. There are exceptions in different markets where the comparative cost between these five N-fertilizers can change in order from the lowest to greatest. The common statement "A Pound of N, Is A Pound Of N" is valid as long as consideration of the movement and loss mechanisms inherent in the N-Cycle are understood and management of specific fertilizer is appropriate as far as timing and placement is concerned.

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Micronutrients for irrigated production

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Introduction

Early work on micronutrients on the prairies dates back to the sixties and identified zinc (Zn), copper (Cu) and manganese (Mn) as potential problem micronutrients. Early work also identified organic (peat) soils as a primary target for micronutrient deficiencies. However, this work also demonstrated that the vast majority of prairie soils were adequately supplied with micronutrients for cereal crops.

Micronutrient research specifically targeted to irrigated crops is very limited and it has been primarily carried out on the Zn requirements of beans. Currently, a number of products and practices are being used or recommended for use without proper experimentation or through experimentation carried out in other parts of North America or the world. Occasionally, the "need" and use of a product or a practice are recommended simply by deduction. Micronutrient maintenance or maintenance of an appropriate nutrient "balance" are also often quoted reasons for micronutrient applications without any experimentation to support such claims.

When Should We Use a Micronutrient?

General

Micronutrients should be used when an **economic** benefit for the **producer** is realized either through yield or quality improvement.

Are Micronutrient Needs for Irrigated Crops Different from those grown under Dryland Conditions?

Under irrigated crops we can consider dryland crops, e.g., CWRS wheat, barley, canola, etc. that are grown under irrigation and an array of specialty crops. The criteria that have been developed for dryland crops need not differ when these crops are grown under irrigation; however, requirements of specialty or strictly irrigated crops, e.g., potatoes, corn, etc. have to be looked at separately. Information on these latter crops is severely limited.

Boron (B)

Recent work (Karamanos et al. 2003b) demonstrated that canola did not respond to B application on 40 sites, even on soils containing <0.15 mg kg^{-1} Hot-water extractable B and with control canola yields of up to 63 bu/acre, thus suggesting that responses to B are rare on prairie soils and in any event hot water extractable B is not an appropriate index to identify B deficiencies.

When Should We Use Boron? Almost never on canola! Alfalfa fields should be closely monitored, however irrigation water may contain sufficient levels of B depending on its source.

Copper (Cu)

A recent compilation of research data on wheat, barley and canola from Saskatchewan and Alberta (Karamanos 2000; Karamanos et al. 2003a) verified a critical level of 0.4 ppm for cereals and 0.3 ppm for canola, respectively. Although responses to Cu have been reported for other crops, such as oats (Malhi et al. 1987), alfalfa (Kruger et al.1984) and flax (Karamanos et al. 1986), the database for these crops is insufficient to draw critical levels from. Commonly, the same criteria are applied equally to all types of soils, although studies have shown that clay soils do not respond as readily as sandy loams or loamy sands (Penney et al. 1988). Penney et al. (1993) showed very little differences in sensitivity to Cu deficiency among five commonly grown wheat varieties in Alberta over seven site-years.

When Should We Use Copper? When **cereals** are grown on soils with **light texture** (sands, loamy sands and sandy loams) with **low organic matter**, high to very high pH (>7.8) and **a soil test** (measured by DTPA) **of less than 0.4 ppm** (0.8 lb/acre in 0-6" depth or 1.2 lb/acre in 0-12"). Rarely would a whole field be deficient in its entirety.

Iron (Fe) and Molybdenum (Mo)

Iron and molybdenum are the two least researched micronutrients in prairie soils primarily because the parent material from which these soils have been developed is rich in these micronutrients. It is highly unlikely that an iron deficiency would be observed under irrigation considering the levels of Fe supplied with the irrigation water. No calibration work has been carried out on these two micronutrients.

When Should We Use Iron and Molybdenum? On agricultural crops, **never**.

Manganese (Mn)

Responses of common crops to manganese on mineral soils in the prairies are extremely rare and work carried out on organic soils (Reid 1982; Loewen-Rodgers et al. 1983; Karamanos et al. 1985; Karamanos et al. 1991; Hartman 1992) is irrelevant to mineral soils.

When Should We Use Manganese? No need, however, research is required on responses of sugar beets to Mn on low Mn soils based on findings in other parts of the world.

Zinc (Zn)

Extensive work on Zn was carried out with beans in Alberta (McKenzie et al. 1999), beans and flax in Manitoba (Loewen-Rodgers 1983: Goh and Karamanos 2004) and a variety of crops in Saskatchewan (Karamanos et al. 1984b; Kruger et al. 1984; Singh 1986; Singh et al. 1987). Singh et al. 1987 were able to verify the commonly used critical level of 0.5 ppm as a valid criterion to assess corn responses to Zn only. Since responses could not be obtained with cereals on soils containing as low levels of Zn as 0.25 ppm, the authors concluded that the critical level for cereals on prairie soils is no greater than 0.25 ppm. In subsequent studies using ^{65}Zn and fractionation techniques, Liang et al (1990; 1991a) demonstrated that DTPA is unsuitable for assessment of "available" Zn in Saskatchewan soils. McKenzie et al. 1999 derived a critical level of 3.0 ppm in coarse soils and 1.5 ppm in medium to fine soils dry bean production under irrigation in southern Alberta. However, earlier work with irrigated wheat, barley and canola in southern Alberta showed no responses of these crops to Zn (McKenzie and Middleton 1991). Recently, Goh and Karamanos (2004) confirmed 0.5 ppm as a critical level for Zn deficiency in beans in Manitoba.

When Should We Use Zinc? On **beans** and **corn** grown under irrigation on soils with **light texture** (sands, loamy sands and sandy loams) with **low organic matter**, high to very high pH (>7.8) and **a soil test** (measured by DTPA) **of less than 0.5 and 0.25 ppm** (1 lb/acre in 0-6" depth or 2 lb/acre in 0-12") , respectively. Caution should be exercised when application rates of major nutrients are "borrowed" from other jurisdictions. A two-year study in Taber, AB (1999-2000) to assess the impact of application of high P rates to potatoes uncovered a P X Zn interaction (Fig. 1a and b) that led to a decrease in potato yield (Fig. 2). This practice will thus result in unnecessary application of Zn to combat the P-induced Zn deficiency.

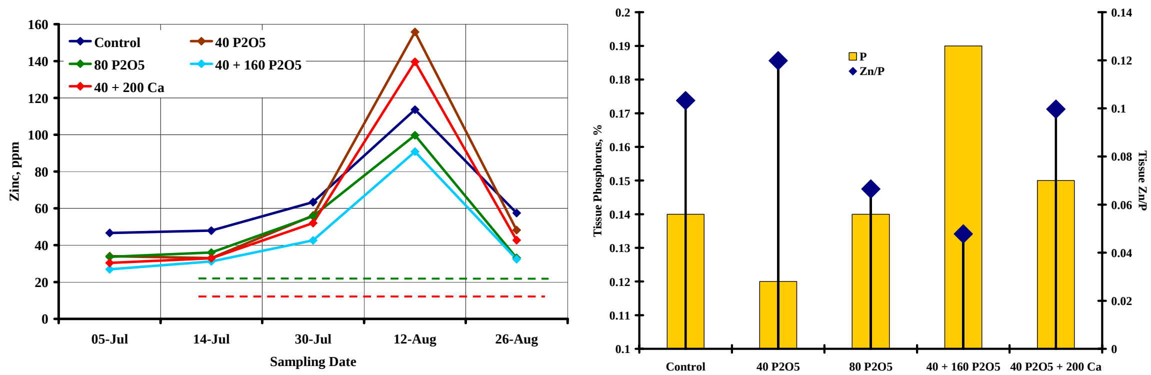

Fig 1. Impact of high P application rates on the petiole Zn concentration of russet potatoes in Taber, AB.

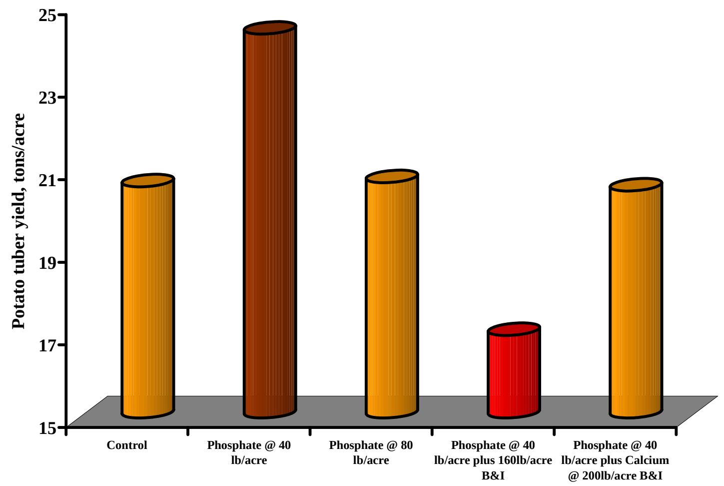

Fig. 2. Application of high P rates to russet potatoes in Taber results in lower tuber yields, presumably due to a P X Zn interaction.

Summary of Interpretive Criteria for Western Canadian Prairie Soils
Results of calibration work of micronutrient soil tests carried out in western Canada are summarized in Table 1.

Table 1. Soil testing criteria for assessing "available" micronutrients in prairie mineral soils.

Nutrient	Extraction method	Crop(s)	Level, ppm	Description	Comments	Economic benefit
Boron	Hot-water	All	Unknown	Inappropriate method of assessment	Criterion of 0.35 ppm irrelevant	None
			>3.5	Toxic	Unconfirmed	--
Copper	DTPA[z]	Cereals	<0.4	Deficient	Sandy to loamy soils	60-80% probability >95% when <0.2 ppm
			0.4-0.6	Marginal	No economic benefit	<10% probability
		Oilseeds	<0.25	Deficient	Sandy soils	<25% probability
			0.25-0.4	Marginal	No economic benefit	None
Manganese	DTPA	All	Unknown		Criterion of 1 ppm irrelevant	None on mineral soils
Zinc	DTPA	Cereals, oilseeds	<0.25	Marginal	Inappropriate method of assessment	<10% probability
		Beans	<0.5	Deficient		75% probability
		Corn	<0.5	Marginal		50% probability

[z] Lindsay (1991)

Plant Analysis

Calibration work for plant tissue test criteria with western Canadian varieties and under prairie conditions is extremely limited. Individual laboratories have derived a variety of criteria from research in other regions of North America or the world and with some varieties that may be irrelevant to western Canada. Karamanos et al. (1984a) were successful in deriving diagnostic criteria for manganese in oats, but Karamanos et al. (1986) and Penney et al (1993) were not successful in establishing plant tissue tests for copper in cereals, canola and flax in western Canada. McAndrew (personal communication) has demonstrated wide differences in plant Zn levels among twelve bean cultivars (Fig. 3). Therefore, much work is needed in this area if "relevant" plant tissue criteria for western Canada are to be derived. Use of petiole analysis, however, is an invaluable tool in assessing N fertility of potatoes throughout the growing season.

Are Micronutrients Needed on Micronutrient Sufficient Soils for "Optimum" Balance to Achieve Maximum Yields?

A number of either soil or foliar applied multi-micronutrient products that are extensively used in other parts of the world have penetrated the western Canadian market based on the premise that their use aids a holistic approach to growing crops. Further claims address an optimum "balance" of all nutrients and especially micronutrients in achieving maximum yields. Indeed an optimum balance of applied nutrients may be of extreme importance in many parts of the world but very little information does exist for western Canadian conditions.

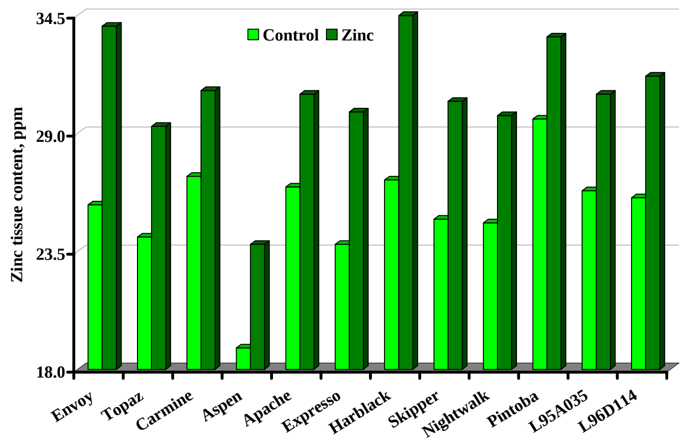

Fig. 3. Plant tissue levels in 12 bean cultivars at 1/10 bloom stage. Only one cultivar (L95A035) responded to Zn. A uniform critical level for Zn would be irrelevant.

We carried out five experiments with barley under irrigation in the Tempest and Lethbridge area from 1991 to 1994 to ascertain whether use of double 5 lb/acre foliar application at tillering and at boot stage of 15-20-20 (also containing 2% S, 0.15% Cu, 0.01% Fe, 0.01% Mn, 0.08% B, 1% Zn and 0.0005% Mo) provided an effective means of alleviating micronutrient deficiencies or simply increased yield due to a "balanced" nutrition. Results are shown in Fig. 4 and clearly indicate that targeting a specific micronutrient to alleviate a deficiency provides a higher economic return than the "shot-gun" approach of multinutrient products.

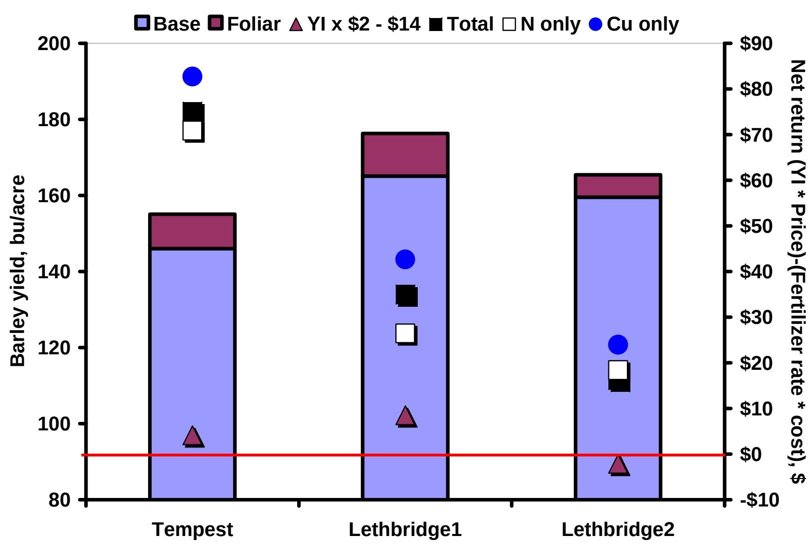

Fig. 4. Response and economic return to a foliar multinutrient product in irrigated barley.

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Understanding how to use manure or compost to optimize irrigated crop production

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ABSTRACT

Land application of livestock manure has caused concern about the build-up of excess nutrients in soil and the potential environmental harm to water quality. Application of manure based on crop-nutrient requirements is considered a beneficial management practice to minimize harmful environmental degradation. The purpose of the paper is to summarize 4 yr of results from a field study where manure and compost were applied at agronomic application rates under irrigated conditions.

INTRODUCTION

Land application is the most effective means of utilizing livestock manure. However, mismanagement of manure can lead to environmental problems (Caldwell 1998). Ultimately, intensive agricultural systems must manage manure on an agronomic basis (i.e. based on crop nutrient requirements) to reduce or prevent soil and water quality problems. Several studies have examined the effects of over-application of manure (Chang and Janzen 1996; Whalen and Chang 2001; Miller et al. 2002; Olson et al. 2003), but there is limited research on the agronomic use of manure in southern Alberta.

In practice, manure is often over-applied and only nitrogen is usually considered when managed agronomically. When other nutrients are considered, particularly phosphorus, challenges emerge such as nutrient imbalances and increased land requirements. In Alberta, the management of manure application on agricultural land is regulated by the Agricultural Operation Practices Act (Province of Alberta 2004). In the Act, manure is applied based on soil nitrate nitrogen (nitrate-N) limits. However, other nutrients, such as phosphorus, are not considered in the Act. Phosphorus loading is a major water quality issue, and agriculture is considered a major source of excess phosphorus (Correll 1998).

The objective of this study was to examine the effects of applying agronomic nitrogen- and phosphorus-based rates of fresh manure and composed cattle manure on soil chemistry and crop yield under irrigation.

MATERIALS AND METHODS

The field site was established about 2 km east of Lethbridge in 2001 on the Canada-Alberta Crop Development Initiative Demonstration Farm. The site is on an Orthic Dark Brown Chernozemic soil. The surface soil (0 to 15 cm) had a clay-loam texture, a pH of 7.3, an electrical conductivity of 0.74 dS m^{-1}, and a 4% organic matter content.

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The experimental design included 10 treatments: control (no added nutrients), fertilizer nitrogen (FN), fertilizer phosphorus (FP), fertilizer nitrogen plus phosphorus (FNP), nitrogen-based manure (MN), phosphorus-based manure (MP), three-times the phosphorus-based manure applied once every 3 yr (MP3), nitrogen-based compost (CN), phosphorus-based compost (CP), and three-times the phosphorus-based compost applied once every 3 yr (CP3). If necessary, supplementary nitrogen fertilizer was also added to the phosphorus-based manure and compost treatments. The source of manure and compost was from feedlot cattle. The treatments were replicated five times and arranged in a randomized block design. Each plot was 6 by 8 m in size.

Soil samples were collected annually in the fall from 2001 to 2005. Samples were taken to a depth of 1.5 m in six incremental layers: 0 to 0.15, 0.15 to 0.3, 0.3 to 0.6, 0.6 to 0.9, 0.9 to 1.2, and 1.2 to 1.5 m. The exception was in 2005 when samples could not be taken below 60 cm because of wet subsoil conditions. The samples were air dried and ground (2-mm sieve) and analysed for extractable nitrate-N and extractable orthophosphate phosphorus (orthophosphate-P) contents.

Commercial nitrogen fertilizer was applied in the spring (2002 to 2005) prior to seeding as banded urea fertilizer (46-0-0). Commercial phosphorus fertilizer was applied with the seed using 0-45-0 fertilizer. Manure and compost were applied by hand and incorporated immediately after application using disks.

Commercial fertilizer, manure, and compost application rates were determined based on soil-test results of extractable nitrate-N (0- to 60-cm layer) and extractable orthophosphate-P (0- to 15-cm layer), assumed total nitrogen and total phosphorus content of moist manure and compost, and predicted nutrient availability from the manure and compost. Contributions of residual nitrogen and phosphorus from the manure and compost were taken into account in subsequent crop years. The amounts of fertilizer, manure, and compost applied for each crop year are shown in Table 1.

The test crops were triticale in 2002, 2003, and 2005, and barley in 2004. The site was irrigated using a solid-set sprinkler system. The plots were harvested at the silage stage using a Hege™ 212 Forage Harvester. Moisture content was determined on chopped subsamples.

RESULTS AND DISCUSSION

Soil Extractable Nitrate-N

The mean nitrate-N concentration among the experimental units ranged from 10.1 to 14.6 mg kg^{-1} at the start of the study in 2001 (Table 2). There were no treatment effects in 2002, but there were significant differences in 2003, 2004, and 2005. Most of the treatments were not significantly different in 2003, except CP3 had significantly larger nitrate-N concentration than FP. In 2004, FN, CP, and CP3 had significantly larger nitrate-N concentrations than the control and FP treatments. In 2005, FN, MP, MP3, CN, and CP3 had significantly larger nitrate-N concentrations than the control and FP treatments. Nitrate-N content in all the treatments decreased in 2002 compared to the baseline year (2001). The nitrate-N content of the two treatments that did not receive nitrogen inputs (i.e. control and FP) continued to decrease in 2003, 2004, and 2005 (control only), whereas the nitrate-N content of the other treatments generally increased in 2003 and then decreased in 2004 and 2005. The decrease in 2005 may have been caused by leaching due to above-normal precipitation. There was no net accumulation of nitrate-N or continued depletion in the treatments that received nitrogen inputs. This suggests that the correct amount of nitrogen was applied to meet agronomic needs of the crop without over-application of the manure or compost.

Table 1. Nitrogen fertilizer, phosphorus fertilizer, manure, and compost application rates.

Treatment	2002 crop year[z,y]	2003 crop year[z,x]	2004 crop year[z,w]	2005 crop year[z,v]
Control	0	0	0	0
N fertilizer (kg ha^{-1})	78	157	134	135
P fertilizer (kg ha^{-1})	22	22	20	20
N + P fertilizer (kg ha^{-1})	78 + 22	157 + 22	146 + 22	157 + 20
N-based manure (Mg ha^{-1})[u]	28.3	38.8	11.1	28.5
P-based manure (Mg ha^{-1}) + N fertilizer (kg ha^{-1})	9.5 + 48.6	1.3 + 140	2.6 + 109	3.8 + 136
3 x P-based manure (Mg ha^{-1}) + N fertilizer (kg ha^{-1})	28.5 + 0	0 + 118	0 + 95	8.8 +109
N-based compost (Mg ha^{-1})	48.4	79	77.7	60.1
P-based compost (Mg ha^{-1}) + N fertilizer (kg ha^{-1})	7.3 + 66.3	7.5 + 140	6.3 + 117	7.1 + 141
3 x P-based compost (Mg ha^{-1}) + N fertilizer (kg ha^{-1})	21.9 + 42.9	0 + 140	0 + 124	24.5 + 123

[z] Fertilizer values are the actual amounts of nitrogen (N) and phosphorus (P) applied. Applied in the spring of the crop year; 46-0-0 urea fertilizer as the nitrogen source, and 0-45-0 as the phosphorus source.
[y] Manure and compost applied on a wet-weight basis in fall 2001.
[x] Manure and compost applied on a wet-weight basis in fall 2002.
[w] Manure and compost applied on a wet-weight basis in spring 2004.
[v] Manure and compost applied on a wet-weight basis in fall 2004.
[u] Mg = megagram = 1000 kg = 1 tonne.

Table 2. The effects of fertilizer, manure, and compost application on nitrate-N concentration in the 0- to 1.5-m soil layer and orthophosphate-P concentration in the 0- to 0.15-m soil layer[z].

		Fertilizer			Manure[y]			Compost[y]		
Year	Control	FN	FP	FNP	MN	MP	MP3	CN	CP	CP3
					Nitrate-N (mg kg^{-1})					
2001[x]	11.2a	9.45a	12.1a	12.6a	8.96a	9.68a	9.96a	12.1a	12.5a	13.8a
2002	5.60a	6.40a	3.04a	5.98a	4.62a	4.88a	4.14a	8.01a	6.47a	8.37a
2003	4.39ab	8.22ab	2.81b	8.19ab	5.99ab	8.50ab	8.86ab	7.82ab	10.3ab	12.1a
2004	2.31bc	10.2a	1.51c	7.42abc	4.42abc	7.22abc	7.10abc	7.96ab	10.6a	8.95a
2005[w]	1.85c	2.85ab	1.64c	2.59abc	2.4abc	3.16a	3.07a	3.37a	2.73abc	3.21a
					Orthophosphate-P (mg kg^{-1})					
2001[x]	9.50a	14.5a	10.7a	14.9a	12.6a	9.20a	12.5a	11.3a	12.5a	9.84a
2002	7.92c	7.82c	10.6c	11.1c	58.6a	18.9bc	37.7ab	35.9ab	11.6c	16.8bc
2003	5.96d	5.57d	13.9cd	9.22d	87.9ab	13.2d	51.5bc	101a	10.9d	13.0d
2004	5.66d	4.95d	16.7cd	14.0cd	112b	16.0cd	38.5c	147a	11.8cd	14.1cd
2005	5.93c	6.10c	19.4c	12.9c	77.2b	12.1c	27.7c	125a	15.6c	25.2c

[z] Means within the same row followed by the same letter are not significantly different (P<0.05).
[y] N = nitrogen-based annual application; P = phosphorus-based annual application; P3 = three times the phosphorus-based application applied once every 3 yr.
[x] Baseline year – parameter values before the application of treatments.
[w] 2005 values are for the 0- to 60-cm soil layer only.

Soil Extractable Orthophosphate-P

Treatment effects on orthophosphate-P concentration were restricted to the 0- to 0.15-m soil layer. Phosphorus is much less mobile in soil than nitrogen. The range in orthophosphate-P concentration in 2001 was 9.4 to 15.1 mg kg^{-1} (Table 2). The nitrogen-based manure and compost treatments caused an increase in orthophosphate-P concentration. After the 2004 crop year, orthophosphate-P increased 8.9 fold in the MN treatment and 13 fold in the CN treatment compared to the control. In 2005, the orthophosphate-P decreased in the top soil layer, possibly due to leaching caused by the above-normal precipitation received in 2005. Most of the phosphorus-based treatments caused little change in soil orthophosphate-P concentration. However, the MP3 treatment caused an increase in orthophosphate-P in 2002 and 2003, and a decrease in 2004 (Table 2). The continued increase in 2003 may indicate the residual manure was still supplying excess crop-available phosphorus. After the 2004 crop season, orthophosphate-P concentration began to deplete, but was still greater than the baseline-year concentration. Possibly the assumptions used for manure underestimated the phosphorus availability, and consequently manure was over-applied. However, this was not apparent in the annually applied phosphorus-based manure treatment (MP). For this treatment, annual soil testing provided a feedback mechanism to make adjustments to annual manure application rates. About half as much manure was applied in the MP treatment compared to the MP3 treatment during the 2002 to 2004 period (Table 1).

Crop Yield

The triticale yield was less in 2002 than in 2003 (Table 3). The average dry-matter yield for the 50 plots in 2002 was 4.9 Mg ha^{-1}, whereas the average yield was 8.4 Mg ha^{-1} in 2003. Growing conditions was not as good in 2002 compared to 2003. In 2002, spring conditions were cooler, the crop did not tiller well, the seeding rate was lower, and minor hail damage occurred to the crop. Barley yield was greater in 2004 than triticale yield in the other 3 yr.

For the most part, there were few significant differences among the treatments. The control treatment consistently produced the lowest yield each year. The FN and FP treatments often had lower yields than the manure and compost treatments. The FNP treatment was not significantly different from any of the manure and compost treatments. Assuming the FNP treatment provided the correct soil fertility status for optimum crop growth, the assumptions used to calculate manure and compost application rates, along with supplemental nitrogen fertilizer for the phosphorus-based treatments, were adequate for optimum crop growth.

CONCLUSIONS

There was no net accumulation of nitrate-N by any of the treatments. In contrast, the MN and CN treatments caused a rapid build-up of orthophosphate-P in the surface soil layer. Manure management, based on agronomic principles, can achieve optimum crop yield, but not necessarily prevent phosphorus build-up, when management is based on the nitrogen requirements of crops. Applying basic nutrient management principles and using a combination of manure and commercial fertilizer can prevent nitrogen and phosphorus accumulation in soil and achieve optimum yield under irrigated conditions.

Table 3. Dry-matter yield means in 2002, 2003, 2004, and 2005^z.

		Fertilizer			Manure ^{y}			Compost ^{y}		
Year	Control	FN	FP	FNP	MN	MP	MP3	CN	CP	CP3
					Dry-matter yield (Mg ha^{-1})					
2002^x	4.4b	4.9ab	4.5ab	5.2ab	5.3a	4.9ab	4.9ab	5.2ab	5.2ab	4.7ab
2003^x	6.4c	7.5bc	7.6bc	8.7ab	9.5a	9.2a	9.3a	9.3a	8.3ab	8.5ab
2004^w	8.2b	9.6ab	9.1ab	10.5a	9.7ab	9.8ab	10.5a	10.9a	9.4ab	10.5a
2005^x	4.9d	6.3bcd	6.0cd	8.2ab	7.0abc	7.1abc	8.1ab	7.9abc	7.9abc	8.5a

^{z} Means within the same row followed by the same letter are not significantly different (*P*<0.05).
^{y} N = nitrogen-based annual application; P = phosphorus-based annual application; P3 = three times the phosphorus-based application applied once every 3 yr.
^{x} Triticale.
^{w} Barley.

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Logistics for manure handling

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Insect thresholds for irrigated crops

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Re-cropping practices after residual herbicide use

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Crop injury caused by herbicide residues became a general concern after the introduction of the first sulfonylurea in 1982. However, injury can occur after the use of several group 2-5 herbicides. These groups include sulfonylureas (Ally, Everest, & Muster) imidazolinones (Assert, Pursuit, & Odyssey), dinitoanilines (Edge & Treflan), synthetic auxins (Lontrel, picloram), and photosynthetic inhibitors (Atrazine, Simazine, Velpar, Sencor). Not all herbicides within each of these groups are persistent and injure following crops, for example, Refine, a sulfonylurea herbicide, did not persist in an active form.

Cropping restrictions following the use of residual herbicides are listed in the Alberta Crop Protection Guide and on herbicide labels. The information in the Crop Protection Guide and labels is based on numerous field trials and additional product experience. For example, DuPont conducted nearly 500 field tests from 1980 to 2003 (Strek 2005) and further modifications to recommendations are sometimes made based on product performance. Soil and weather conditions that affect herbicide persistence and injury to following crops are also described in the Crop Protection Guide. However it is impossible to anticipate all future weather conditions and soil properties where herbicides will be used before they are sold to producers and herbicide labels are developed.

A complex list of factors that influence herbicide persistence and the activity of the residues were summarized by Helling (2005) and Maurice (2005). Injury to following crops is influenced by herbicide adsorption to soil and the rate of degradation. If an herbicide is strongly adsorbed to soil then it will not be very available for plant uptake or degradation by soil microbes. Paraquat for example is strongly adsorbed by soil (adsorbed to clay) and also very persistent but not available for plant uptake; therefore, it does not injure following crops (Moyer and Lindwall 1985). Sulfonylurea herbicides are not strongly adsorbed to soils with low organic matter content and some of them can be fairly persistent; therefore their residues can be readily taken up by crops and severe following crop injury can occur (Moyer 1995). However, in soils with high organic matter content sulfonylurea herbicides are adsorbed to a degree that their toxicity to following crops is greatly reduced (Moyer and Hamman 2001). Soil pH can affect both the chemical hydrolysis of some herbicides and their adsorption to soil. Sulfonylurea herbicides are degraded fairly rapidly by chemical hydrolysis at low pH but some of them persist in high pH soil. Imidazolinone herbicides seem to be more persistent in low pH soils (Shaner and Hornford 2005) especially under drought conditions.

For those herbicides that are degraded by soil microbes, at very low moisture content microbial activity and herbicide degradation are almost zero. The rate of dissipation increases by 1.5 to 2 times when soil water content increases from ½ field capacity to field capacity. Degradation of herbicides by chemical hydrolysis is likely less affected by soil moisture.

Temperature also influences herbicide degradation. The rate of herbicide dissipation increases 2 to 3 times for each 10° C rise in temperature. For herbicides that are degraded by microorganisms, degradation is at an optimum rate at 30° C. Due to our climate, herbicides are more persistent on the Canadian Prairies then in a lot of agricultural areas; therefore, re-cropping guidelines must be developed under Canadian field conditions.

Several ALS inhibitor herbicides are available for weed control in a number of different crops. Therefore, although not recommended, the sequential application of ALS inhibitor or group 2 herbicides for two or more years is possible. There is a concern that these sequential applications may lead to severe injury to following crops that are not tolerant to group 2 herbicides. Recent research by Johnson et al. (2005) indicate that long-term repeated application of these herbicides did not generally result in toxic levels of group 2 residues in soil. However, in certain conditions, especially where there was low rainfall and low soil organic matter, toxic levels of herbicide residues did accumulate. In some instances the effect of residues from sequential annual group 2 applications was greater than the expected additive effect from each herbicide on a non-tolerant crop in the third year (Johnson et al. 2005).

Over the last 20 years we have collected a lot of information about the effect of residual herbicides on following crops and used this information to develop fairly good guidelines for re-cropping. However, there are still unusual weather patterns or combinations of weather patterns and soil properties that are not covered by previous experience and crop losses can occur when current recommendations are followed. Usually an explanation can be found after crop injury occurs but to predict all situations where injury will occur is more difficult.

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Field crop disease review for 2005 and forecast for 2006

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Introduction

The 2005 growing season presented many challenges for field crop producers in southern Alberta. While weather conditions favored good crop growth, they also promoted the development of a number of infectious and non-infectious diseases. Growers who followed an integrated disease management program, with the emphasis on prevention, generally fared better that those who relied upon a reactive approach if and when diseases appeared in their crops. In this presentation, I would like to highlight some of the more common diseases observed in field crops in southern Alberta in 2005 and to attempt to forecast what might happen in 2006.

The 2005 Growing Season in Review

Much like in 2004, the 2005 growing season started out cool and dry in many areas of southern Alberta. Winterkilling in fall-seeded cereals and perennial forages was not as great as in 2004. Regrowth of pasture and hay crops was slower than usual because of the low temperatures and lack of moisture, and these conditions also delayed spring seeding in some areas. Late frosts damaged sugar beet and canola crops and necessitated some reseeding. Frequent rain showers and some deluges in early June improved soil moisture conditions in many areas; however, some crops were damaged by flooding, especially in western areas of the region. Delayed emergence in some crops resulted in stands with variable maturity. Wet soil conditions also promoted decay and damping-off in some late-seeded special crops. Fertilizer leaching and saturated soils also led to the appearance of yellow patches in low-lying areas of some fields.

While the rains in June promoted good growth in crop, hay and pasture stands, they also favored the development of foliar diseases, such as downy mildew, bacterial blight and rust. Several severe hailstorms caused major damage in several fields across the southern region. The return to more seasonable growing conditions in July promoted rapid growth in most crops. Leaf spots, sclerotinia stem rot and gray mold were reported in many crops, and late blight made an appearance in a few potato fields. Lush canopies created humid conditions that were favourable to the spread and development of these diseases. Rain showers and cool temperatures in August promoted some late season disease development and led some producers to apply additional fungicide sprays. Some swathed hay and cereal crops deteriorated as the result of wet weather and poor drying conditions. Rain showers persisted into September in some areas, which delayed swathing and harvesting. Although the yields of harvested crops were above average in many cases, the quality was variable. Harvesting continued into November in some areas, and frost damage, weathering, staining and sprouting in the swath affected the quality of some cereal and specialty crops. Some potato and bean fields were passed over for harvesting because of weather damage.

Cereal Disease Situation

Leaf diseases such as net blotch on barley and tan spot on wheat were prevalent, especially where barley-on-barley or wheat-on-wheat rotations were followed. Some “green-bridge” diseases, such as wheat streak mosaic, barley yellow dwarf and the root rot complex were noted in fields with poor rotation schemes. Head and kernel diseases were prevalent as a result of the humid growing conditions. Take-all root rot caused significant damage in several fields where wheat was replanted into wheat stubble. Stripe rust showed up in winter and spring wheat crops in early July and caused some damage in fields as far north as Lacombe. This disease was also observed to be severe in a barley nursery at Edmonton. It was not clear whether stripe rust over-wintered in Alberta in 2004-05. Airborne spore showers from the Pacific Northwest region of the United States are believed to the major source of inoculum for our cereal crops. Leaf rust showed up in wheat crops in the Barons/Claresholm area in early August. Those that had been seeded early and were already in the early dough stage required no fungicide sprays; however, some late-seeded crops required at least one application. In general, early seeded crops seemed to have less disease problems than those that were planted later. Eyespot, a fungal disease that infects the crown and leaf sheaths, was observed in a few wheat fields.

Fusarium head blight did not appear to be a significant problem in the field in 2005. Cool temperatures during the flowering period were not very favourable to infection by the *Fusarium* fungus, even though humidity conditions were relatively high in many fields. Approximately 41 wheat fields from the Peace Region to Oyen were surveyed for fusarium head blight (FHB) in 2005. Twenty-one fields (55%) had FHB symptoms, with incidence levels ranging from 0.3 to 4.7%. These levels were comparable to those seen in 2004. No *Fusarium graminearum* was detected from heads exhibiting symptoms. The most common *Fusarium* spp. isolated from symptomatic heads were *F. avenaceum* and *F. poae*. An analysis of *Fusarium*-damaged wheat kernels (FDK) from the 2005 crop by the Canadian Grain Commission, Winnipeg, in 2005 showed that *F. graminearum* was present in all crop districts, but was found in CDs 1 and 2 at proportionately higher levels than in CDs 3-7 (Table 1, Figure 1). Overall, the percentage of FDK in grain samples from Alberta remained relatively small.

Table 1. Analysis of *Fusarium*-damaged wheat kernels (all classes combined) from Alberta by the Canadian Grain Commission, Winnipeg, Manitoba in 2005.

Crop District	Number of samples tested	Number of FDK plated	*Fusarium graminearum*	*Fusarium avenaceum*	*Fusarium culmorum*	*Septoria nodorum*
1	Sum of 35	240	68	36	42	41
Southeast	Average of 35	6.9	1.94	1.0	1.2	1.2
Region	% of FDK		28%	15%	18%	17%
2	Sum of 155	1183	267	213	99	525
South-central	Average of 155	7.6	1.72	1.4	0.6	3.4
Region	% of FDK		23%	18%	8%	44%
3	Sum of 50	722	14	151	7	434
Southwest	Average of 50	14.4	0.28	3.0	0.1	8.7
Region	% of FDK		2%	21%	1%	60%
4	Sum of 166	2156	3	1277	23	625
East-central	Average of 166	13.0	0.02	7.7	0.1	3.8
Region	% of FDK		0.1%	59%	1%	29%
5	Sum of 66	996	4	530	33	293
Central	Average of 66	15.1	0.06	8.0	0.5	4.4
Region	% of FDK		0.4%	53%	3%	29%
6	Sum of 32	325	2	186	7	74
Northeast	Average of 32	10.2	0.06	5.8	0.2	2.3
Region	% of FDK		0.6%	57%	2%	23%
7	Sum of 64	295	3	55	33	99
Peace Region	Average of 64	4.6	0.05	0.9	0.5	1.5
	% of FDK		1%	19%	11%	34%

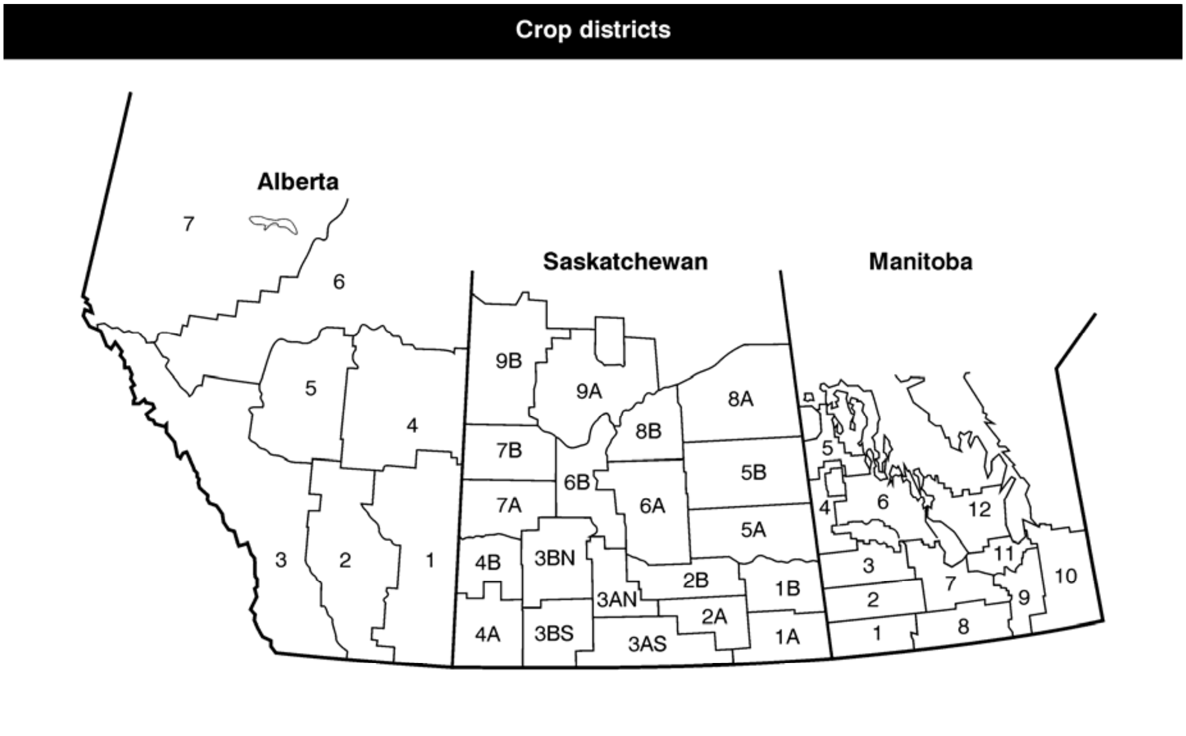

Figure 1. Crop districts of Alberta, Saskatchewan and Manitoba.

Oilseed Crop Disease Situation
Canola disease surveys in southern Alberta in 2005 were much less extensive than in 2004. No commercial fields with fusarium wilt were found anywhere in Alberta this year. The elimination of susceptible varieties is believed to be mostly responsible for this trend, although the cool, wet weather also may have slowed disease development. No fields with severe blackleg were detected. Many canola producers remain concerned about a new race of blackleg called PG4, which has been found in central Alberta and appears to be more virulent than the common strains PG2 and PG3 because of its ability to attack previously resistant varieties. Tests of Alberta canola seed by 20/20 Seed Labs at Nisku in early 2005 revealed that only one sample had the virulent blackleg fungus, *Leptosphaeria maculans,* while 29.5% had *L. biglobosa* (weakly virulent blackleg fungus).

Clubroot, a soil-borne disease of canola and cruciferous vegetables that was found for the first time in Alberta in 2003, was detected in 41 of 151 canola fields surveyed in central and east-central Alberta this summer. Most of the infested fields were located north and northeast of Edmonton. Eight had a high incidence of the disease (>70% infected plants), 21 had an intermediate incidence, and 12 had a low incidence. This disease was not found in any canola fields in 2004. The cool, wet, growing conditions in 2005 appeared to favour clubroot development. This disease is also of concern to cole crop vegetable producers. A survey of 15 fields of cabbage, cauliflower, broccoli, brussels sprouts and related crops in the Edmonton area in late August and early September revealed two occurrences of clubroot, one of which caused an estimated 50% yield loss in a field of cauliflower near Leduc.

Forage Crop Disease Situation
Foliar diseases, such as spring black stem, downy mildew and yellow leaf spot, were prevalent in some alfalfa seed fields and one or more fungicide sprays were applied. Likewise, leaf spots, rust and/or powdery mildew were common in some grass seed fields. Reduced activity of leafcutter bees contributed to poor yields in some alfalfa seed fields. Untimely rains at swathing and harvest delayed drying and reduced seed quality in several fields of grass and alfalfa seed, as well as in perennial forage crops grown for hay.

Pulse Crop Disease Situation
Ascochyta blight started early on chickpeas and disease development was favored by the cool, rainy weather. Heavy infection was noticed in fields planted with diseased seed or where new fields were situated adjacent to those that had grown chickpeas in 2004. Some growers sprayed three or more times in an effort to arrest ascochyta blight. The disease pressure eased with the return of hot weather in July, but fall precipitation favored late-season disease development and delayed harvest in areas west of Taber. Most growers in the Warner-Foremost area were able to complete their harvesting prior to the wet weather. An unusual situation in which chickpea seed sprouted in the pod was noticed in some fields. The condition seemed worse in fields that were desiccated but not harvested prior to the rains. Crops that weren't desiccated seemed to escape the problem. Pods near the top of the plant were more seriously affected than those near the bottom. The ripe pods seemed to absorb and retain the moisture more than the green pods did. Saprophytic molds also developed on these plants. No formal disease surveys were carried out on chickpeas in 2005.

Lentil crops appeared healthy through most of the season and yields were good. Seedling blight, root rot and gray mold were observed in a few fields. An unidentified white leaf-spotting symptom of unknown cause was present in a few fields, but caused relatively little damage.

Bacterial blight occurred at high levels in a few pea fields in the Warner area early in the season, undoubtedly favoured by rainy weather. Disease development slowed considerably in July, when hot weather prevailed. Downy mildew also appeared in many fields early in the season and stunted the new growth. The ascochyta/mycosphaerella blight complex was also present in many fields and necessitated some spraying with foliar fungicides. Powdery mildew was also seen in some fields.

Average to above-average levels of white mold were seen in dry bean fields in 2005 as a result of favourable environmental conditions for disease development. Growers adjusted their spray programs with Lance fungicide and the product seemed to work better than in 2004, when it was first introduced to the Canadian market. Halo and common blight were present in a few fields and were made worse by hail damage. Bacterial wilt was also observed in a few fields. Early yellowing syndrome, a premature senescence phenomenon in bean crops, was observed in several fields in the Taber area in late August. Salinity, wet soil conditions and/or root rot were implicated in some cases.

Disease Forecast for 2006
Both infectious and non-infectious plant diseases are a fact of life for crop producers in southern Alberta, regardless of the type of crop being grown. Diseases are usually more common and have a greater impact in years when the growing conditions are warm and wet or cool and wet compared to when they are warm and dry or cool and dry.

Non-infectious diseases are caused by environmental stresses, such as extreme temperatures, excesses or deficiencies of nutrients or water, pesticide or fertilizer misapplication, physical injury and the like. These problems occur year in and year out. Some of the causal stresses can be lessened or avoided by following recommended cultural practices, while others, such as climatic conditions, are beyond the control of the grower. Infectious diseases are caused by plant pathogenic bacteria, fungi, viruses, nematodes and related biotic agents. For these kinds of diseases to establish and develop, three key factors must be present at the same time. These are suitable environmental conditions, a susceptible plant and a virulent pathogen. Together, these factors comprise the so-called “disease triangle.” All three of these components must be taken into consideration when attempting to forecast the potential for disease outbreaks in 2006. Let’s look at each one in turn.

Host Susceptibility – Despite the advances that have been made the development of field crops with resistance or tolerance to specific diseases, most are still susceptible to many of the major pathogens that commonly occur in southern Alberta. Some examples are the seedling blight and root rot pathogens *Pythium*, *Rhizoctonia*, *Gaeumannomyces* and *Fusarium*, the stem rot pathogens *Sclerotinia* and *Botrytis*, the leaf spot pathogens *Septoria* and *Ascochyta*, the mildew pathogens *Erysiphe* and *Peronospora*, and the head blight pathogens *Claviceps* and *Fusarium*.

Pathogens - Many of the diseases that occurred in our field crops this past season will overwinter in the soil or on infested crop residues. Some examples are sclerotinia stem rot (canola and pulses), tan spot and septoria (wheat), net blotch and scald (barley), common root rot, take-all root rot and fusarium head blight (cereals), ascochyta blight (chickpea), mycosphaerella blight and powdery mildew (field pea), and leaf spots (forage grasses and legumes). High levels of infection by several of these diseases in 2005 means that there will be abundant inoculum available to infect new crops in 2006, especially in fields where infected crops were grown last year. Replanting susceptible crops in these fields should be avoided.

Environmental Conditions - Weather patterns during the growing season can have a profound effect on the occurrence and impact of diseases in virtually every kind of crop grown in Alberta. The highly variable and often unpredictable nature of the weather patterns in our province introduces a high degree of uncertainty into any predictions of what the crop disease situation might be like this year. *The Old Farmer’s Almanac* is a time-honoured publication that provides reasonably accurate long-range weather predictions. The 2006 edition predicts that the winter season will be much milder than normal in the Prairie Region, with temperatures two or three degrees above normal on average. The coldest periods will occur in mid-January and mid-February. Snowfall will be near normal, on average, with below-normal snowfall in the east and near- or above-normal levels in the west. The heaviest widespread snowfall will occur in mid-February. The *Almanac* suggests that temperatures in April and May will be near normal, with below-normal precipitation. Late May is expected to be unusually hot. The summer season will have above-average temperatures and below-normal rainfall. The hottest temperatures will occur in late June, early and late July and early to mid-August. September and October will be have below normal temperatures and near-normal precipitation. The heaviest snowfall will occur in mid-October. If this long-range forecast is true, environmental conditions will be less favourable for the development of many of our economically important crop diseases in 2006 than they were in 2004 and 2005. Below-normal rainfall and above-average temperatures in the spring and summer should deter infection and spread by most of the common bacterial and fungal pathogens in both irrigated and dryland crops.

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Irrigation and plant disease management

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Introduction

The most important risk factor influencing the development of plant disease is the weather. Particular weather conditions can have a positive, negative, or neutral influence on disease development. Overall, the most important weather parameter is moisture. In general, frequent showers and high humidity produce conditions that favour disease development. However, heavy rainfall may not always favour disease, as it tends to wash pathogen spores from the air and off of plants. Temperature can also be important, especially at the extremes. Temperatures that are either low (typically $<10^oC$) or high (typically $>30^oC$) can inhibit or slow down the pathogen's ability to reproduce and infect the host as well as limit subsequent disease development. Overall, moderate temperatures (typically $15-25^oC$) in combination with frequent showers produce conditions that can lead to rapid disease development.

Strategies for plant disease management relate to the components of the "disease risk triangle", which is a diagrammatic representation of what is required for a plant disease to occur. The presence of a virulent pathogen in sufficient quantity, the occurrence of favourable weather conditions, and the presence of a susceptible host are all needed for disease development. Producers typically manipulate the components of the "disease triangle" to reduce disease risk. Although producers have little or no control over broad environmental conditions during the growing season they may be able to modify the microenvironment within the crop to limit conditions that favour disease development. Producers growing small grain cereals under irrigation may be able to reduce disease risk by careful water management. The focus of this paper is to provide a brief introduction to the role irrigation plays in relation to disease risk and how it may impact the risk of fusarium head blight of cereals.

How does irrigation influence plant disease risk?

Moisture arrives in the crop canopy from various sources including rain, dew, fog, and irrigation and is stored in various components of the crop volume, where it can potentially influence disease development. Irrigation is an artificial means of introducing water into the cropping system so as to promote plant development in dry environments that otherwise may not support crop production. However, high temperatures, long periods of sunshine and lack of substantial rainfall during may help to limit any influence that irrigation may have. Evapotranspirational water loss from crops during periods of increased temperature and wind speed, and sunny conditions may be high enough to restrict soil moisture levels despite irrigation, especially when crops have not completely covered the soil surface at earlier growth stages or where a light stand occurs.

Rotem and Palti (1969) indicated that irrigation leads to the production of a dense crop stand, thus influencing the microenvironment within the crop canopy. The impact of irrigation on modifying the canopy microenvironment typically increases as the crop canopy density increases and where macroenvironmental conditions are "suboptimal" to "marginal" for disease development (Rotem and Palti 1969). Irrigation, especially sprinkler irrigation, results in a reduction in canopy temperature, while increasing relative humidity and the period of leaf wetness (Rotem and Palti 1969). As Rotem and Palti (1969) have suggested, irrigation influences disease development not only via an impact on conditions that favour host infection, but also in terms of pathogen sporulation and subsequent spore dispersal. Wetting of pathogen-infested crop residue initiates and promotes pathogen sporulation, especially where a dense crop canopy has developed that can maintain humid conditions resulting from irrigation for a longer period of time. Dispersal of pathogen spores may occur as a result of the direct impact of droplets (rain-splash dispersal) of irrigation water or via the necessary hydration of specialized fruiting bodies, such as perithecia.

The type of irrigation can also be very important in terms of disease risk (Rotem and Palti 1969). Sprinkler irrigation results in wetting of the entire crop canopy and soil surface compared to furrow or flood irrigation and as a consequence may increase the risk of foliar diseases. Rotem and Palti (1969) also indicated that the amount, frequency, and rate of irrigation can be important for disease risk. Increasing application frequency of sprinkler irrigation at increased rates and amounts can lead to increased disease risk. Although irrigation can lead to an increase in disease risk, producers can limit this risk via irrigation management (Rotem and Palti 1969). Surface irrigation such as flood or furrow irrigation can be used to limit disease risk, but use of these irrigation methods may not be practical or economical. With sprinkler irrigation, the risk of disease can be somewhat mitigated by avoiding excess fertility, which can result in extremely dense crop canopies, which favour disease development. Decreasing the frequency of irrigation can also reduce the risk of disease, but this will need to be balanced with the water needs of the crop (Rotem and Palti 1969).

Irrigation and fusarium head blight

From recent field studies at Brandon, MB in 2001, 2002 and 2003, irrigation treatment was influential in the development of fusarium head blight (FHB). In 2002 and 2003, termination of irrigation prior to anthesis produced lower FHB index values than continual irrigation throughout anthesis. During 2001-2003, the type of irrigation management also influenced yield. Higher yields were observed with flood irrigation (days 3 and 5 of anthesis) than with sprinkler irrigation (days 3 and 5 of anthesis). In all three years, highest mean yield values (over fungicide treatments) were observed with flood irrigation at days 3 and 5. However, termination of irrigation prior to anthesis resulted in reduced yields compared with continual irrigation, but only in 2003 when FHB levels were lower. In addition to reducing FHB levels, DON levels were also reduced with the termination of sprinkler irrigation prior to anthesis or the use of intermittent sprinkler irrigation as compared to continual irrigation throughout anthesis in 2002 and 2003.

Other research conducted in southern Alberta in 2002 and 2003, as well as results from FHB symptom surveys from 2001-2004, and assessment of field characteristics of *F. graminearum*-positive samples from the Canadian Grain Commission's new crop surveys in 2002 and 2003 have looked at irrigation and FHB in wheat. Results from these studies showed that the presence and increased level of FHB and percentage seed infection with *F. graminearum* were more commonly associated with wheat under irrigation compared with dryland production. There was some indication that increasing amounts of irrigation (10-14 inches from late June to early August) during the summer were also associated with higher incidence of FHB and levels of *Fusarium* spp. seed infection, especially when combined with highly susceptible varieties and lack of crop rotations of a suitable length. Similar results were found by Strausbaugh and Maloy (1986) in Washington State, where scab, caused by various *Fusarium* spp. including *F. graminearum*, was found in irrigated fields, but not in dryland wheat fields. They also found that the scab severity was higher when sprinkler irrigation (center-pivot irrigation) was used compared to fields using rill (surface) irrigation. Strausbaugh and Maloy (1986) also found that scab severity was higher in an area (average 0.08 ha) immediately around the center of the pivot-irrigation system. They suggested that this may be due to the crop and soil closest to the pivot center remaining more humid; in this area the pivot would be moving more slowly compared to areas farther from the center of the pivot irrigation system. However, recent studies in southern Alberta showed similar levels of disease occurred in most fields whether samples were collected in an area of the field closest to the irrigation pivot center or as the distance increased up to 300 m.

Overall, recent studies at AAFC Brandon have indicated that termination of irrigation just prior to flowering may have a beneficial impact on disease levels, while maintaining yields when the risk of FHB is high. There was also some benefit associated with intermittent irrigation during flowering as compared with continual irrigation. The irrigation treatment differences observed in the Brandon irrigation study were likely smaller than what would be expected under the drier conditions typically experienced in the irrigated regions of southern Alberta. Environmental conditions are much drier at Lethbridge and Medicine Hat compared to Brandon, while temperatures are similar. Moister conditions at Brandon likely compensated for some of the irrigation treatments that were used. Brandon was chosen as the location of the irrigation experiment based on concerns related to the Alberta Fusarium response plan and the declaration of *F. graminearum* as a designated pest (Anon. 2001; Ali and Calpas 2002). Researchers wanted to avoid setting up a field experiment in Alberta that may have promoted the development and establishment of *F. graminearum*, especially given that it is a designated pest (Anon. 2001).

The most difficult aspect of irrigation management for FHB control in the irrigated dry regions of southern Alberta will be trying to balance the water requirements of the crop versus the need to reduce the risk of FHB. Efetha (2003) has produced a set of recommendations to help producers meet the water needs of their cereal crops, but at the same time reduce the risk of FHB and potential DON contamination of harvested grain. Other pathologists with extensive FHB experience have indicated that irrigation should not be applied for 5-10 days after flowering to help limit humid conditions that favour infection (M. McMullen and B. Stack, North Dakota State University, personal communication). This is consistent with the results and interpretation from recent irrigation studies in Brandon and southern Alberta. In addition, it is recommended that producers consider increasing seeding rates, as this helps to reduce tiller formation and shortens the flowering period for all plants in a field, thus reducing the time that irrigation should be avoided (M. McMullen and B. Stack, North Dakota State University, personal communication).

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The R.A.T. of irrigation management: The future for improving irrigation efficiencies

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The challenge for irrigated agriculture in all developed and developing countries is to increase food production with existing water allotments or to even increase food production with less water allotted to irrigated agriculture (Smith and Munoz, 2002). The effective and sustainable use of water allocated for agriculture has become a critical concern in many areas of the world. Howell (1996) wrote, "*Water conservation and irrigation management have never held mor1e promise or preeminence in common everyday lives*."

The issue and concern is not new and throughout many parts of the world, research has been conducted to either minimize or address the adverse effects of irrigated agriculture, strive for efficiencies to maximize irrigation application effectiveness or utilize various training and technologies to enhance the efficiency of irrigated agriculture (Melvin and Payero, 2003). A workshop held in Portugal in 1994 titled "Sustainability of Irrigated Agriculture" emphasized that increased production and/or intensification must come from irrigated agriculture (Periera et al., 1996).

Advances in irrigation system technologies have, perhaps more than any single development in irrigated agriculture, improved the efficiency of water diverted for irrigation. The efficiency of low-pressure, drop tube center pivot irrigation systems is currently at or above 80 %. Efficiencies at or above 90% are possible with surface or sub-surface drip technologies. Continued improvements in technologies to increase water use efficiencies are limited; system efficiencies are at or near their maximums. Future efforts for improving irrigation efficiency must, in large part, come about through improved irrigation management, irrigation information or both.

In many parts of the world, good irrigation management is not just a desirable goal but also a requirement (Burt et al., 2001). Irrigation management is a planning and decision-making activity to determine when to irrigate a crop and how much water to apply. However the desired goals of irrigation management can vary depending on factors such as the amount and value of irrigation water, the value of the crop grown, competition for existing water supplies and government policy for water conservation and use. The goals can include:

- Apply the maximum amount of water to achieve maximum yields.
- Obtain maximum amount of water use efficiency or crop yield per unit of water input.
- Input water to a level where the price of the last unit of water applied is equal to the revenue obtained as a result of its application (English, 2002).

Desired information needed for informed irrigation management decision-making includes (Jensen et al., 1990):

- Soil physical properties.
- Current level of soil moisture in field.
- Current or expected depletion rate (evapotranspiration) of crop.

- Allowable depletion of soil moisture dependent on crop grown and stage of crop.
- Amount of water that should be applied.
- Application rate of equipment used.

Summarizing, for informed irrigation management, irrigators must be knowledgeable on soil physical/hydrologic properties; crop water use and evaporation rates; plant response at various stages to soil moisture and soil moisture stress; irrigation equipment and methods for determining soil moisture levels.

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Irrigating to enhance quality and yield

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INTRODUCTION

The purpose of irrigation management is to maximize crop production and quality, while efficiently utilizing irrigation water and associated equipment (Alberta Agriculture, 1985). Insufficient soil water can negatively impact a crop by decreasing potential crop yield (forage and seed) and quality. Negative impacts on crops can be a result of water stress during reproductive stages, due to pre-mature ripening or because of light kernel weight.

Excess soil water can also have a negative impact on crop yield due to restricted root development from a lack of soil air, by promotion of crop disease, and by increasing the potential for crop lodging. In addition, excess irrigation can lead to wasted water via surface runoff, evaporation and deep percolation and wasted nutrients lost due to leaching. In a time of escalating energy prices, excess irrigation also translates to unnecessary cost.

When irrigating to enhance crop yield and quality there are many factors that need consideration, including crop, variety and stage of growth, soil type, irrigation equipment used and climate during the growing season. The following will briefly summarize the soil physical characteristics and crop characteristics that must be understood for effective irrigation management.

SOIL PHYSICAL CHARACTERISTICS

Table 1 shows some soil characteristics, relevant to irrigation management, for several different soil textures. The total porosity is the volume of a soil that is not occupied by the solid soil matrix, which includes mineral and organic materials. This porous volume may be occupied by air and water, both of which are necessary for crops to thrive. The wilting point, sometimes called permanent wilting point, is defined as the soil water content at which a plant can no longer exert enough energy to draw water into its roots from the soil. If the soil water surrounding the roots is allowed to deplete to the wilting point, adding water will not revive the plant (Ley et al., 2005). The field capacity of a soil is the soil water content after a saturated soil is allowed to drain freely until internal drainage due to gravity becomes negligible, which takes a few hours to a few days, depending on soil texture (Ley et al., 2005). The available water holding capacity is the difference between field capacity and wilting point. Table 1 shows the average available water holding capacity for several texture classes of soil. Here, it is given as a percent by volume as well as the millimetres of water per metre depth of soil. Figure 1 shows a graphic representation, called the “bucket model” of the available water holding capacity of a clay loam soil (Hillel, 1998). So, for example, a clay loam soil with a wilting point of 16% and a field capacity of 36% has a water holding capacity of 20% by volume or 200 mm of water per 1 m depth of soil (Table 1). This soil is at 50% of available water holding capacity when the soil water content is at 26% by volume (Figure 1). Crop irrigation management recommendations are traditionally given as the % of available water (Figure 1).

It is evident that different soil textures can differ greatly in wilting point, field capacity and the resulting water holding capacity. The data given are averages and there are actually ranges within each texture category. For example a clay loam, on average has a field capacity of 36% but, in southern Alberta, this value can in fact range from 31% to 41% (Alberta Agriculture, Food and Rural Development, 2004b). Because of the large potential variability in soil water holding capacity, irrigation management recommendations are given as a proportion of available water.

The surface infiltration rate of water into soil also varies with soil texture. Water will infiltrate into a saturated loamy sand at up to 60 mm/h, whereas a saturated clay soil will have an average infiltration rate of only 0.6 mm/h, a difference of 100 times (Table 1). In order to prevent runoff, it is essential that the irrigation rate is equal to or less than the infiltration rate (Alberta Agriculture, Food and Rural Development, 2004a). So it is clear why it is critical to have a thorough knowledge of the soil physical properties for any given field for effective irrigation management. It is also important to note that soil topography and texture can vary within a field, so, different crop responses can be expected across a field, even if irrigation applications are equal. Knowledge of the spatial variability of soil texture within a field is also valuable information to scheduling irrigation for maximizing crop yield and quality.

MONITORING SOIL WATER CONTENT

For efficient irrigation management, soil water content should be monitored on a weekly basis throughout the growing season. This can be done by the feel method of cored samples, with numerous soil moisture sensors, by direct measurement of crop use or with crop water use models (Alberta Agriculture, Food and Rural Development, 2005). Rainfall and irrigation application rates and volumes should be carefully monitored and used with data on soil physical properties to schedule irrigation (Alberta Agriculture, Food and Rural Development, 2004a).

CROP CHARACTERISTICS

Crop irrigation needs depend on the type and variety of crop grown, the stage of growth (rooting depth), target yield and crop management (Alberta Agriculture, Food and Rural Development, 2004a).

Irrigation demands may differ between varieties. For example, due to plant genetics and an earlier maturity date, the Polish varieties of canola have lower water requirements than Argentine varieties (Alberta Agriculture, Food and Rural Development, 2002b).

Irrigation needs also depend on the ultimate purpose of the crop being grown. For example, irrigation strategies for alfalfa grown for seed must take into account the canopy temperature. In order to promote pollination by leafcutter bees, irrigation applications must be limited to allow canopy temperatures to remain above 21ºC (Alberta Agriculture, Food and Rural Development, 2002a). This practice is not necessary for alfalfa grown for forage.

Table 1. Soil physical characteristics for several texture classes.

Soil texture	Total porosity	Wilting point	Field capacity	Available water holding capacity		Saturated infiltration rate
	(%)	(% volume)		(% volume)	(mm/m)	(mm/h)
Loamy Sand	40	6	16	10	100	26-60
Sandy Loam	42	8	22	14	140	25.6
Loam	43	12	30	18	180	6.8
Sandy Clay Loam	45	13	29	16	160	4.3
Silt Loam	45	10	30	20	200	13.2
Clay Loam	47	16	36	20	200	2.3
Silty Clay Loam	47	18	40	22	220	1.5
Sandy Clay	45	20	37	17	170	1.2
Silty Clay	47	25	46	21	210	1.0
Clay	49	23	42	19	190	0.6

(Adapted from Alberta Agriculture, Food and Rural Development, 2004a and 2004b)

Table 2. Summary of irrigation requirements for several crops.

Crop	Estimated growing season crop water use (mm)	Allowable depletion (to % of available water)	Effective crop rooting depth (m)	Proportion of water (%) from surface depth (m)	Growth stage that crop is most sensitive to water stress	Agdex #
Alfalfa		40	1.2			
Forage	620					561-14
Seed	510					100/32-1
Barley		50		70% from 0.5m	tillering and throughout flowering	561-15
Forage	390					
Malt	430					
Canola	480	50	1.2	70% from 0.5m	late vegetation/ spiking and throughout flowering	561-5
Corn		50	1.0		25-30cm tassel and ear initiation	100/32-1 U of Nebraska
Fresh	430					
Silage	510					
Dry beans	368	60	0.9	80% from 0.6m	late vegetation and throughout flowering and pod formation	561-12
Flaxseed	410	50	1.0	70% from 0.5m	flowering to seed ripening	561-8
Peas		60	0.8	70% from 0.4m	throughout flowering and into pod development and filling	561-11
Dry	400					
Fresh	375					
Potatoes	520		0.8	80% from 0.5m	late budding and throughout flowering	561-10
Sugar beets	560	65	1.0	70% from 0.6m	throughout the growing season	561-6
Timothy	400-500	50	0.75	80% from 0.5m	flowering	interim report
Wheat		50	1.0	70% from 0.5m	tillering and flowering	
Soft	480					561-13
Hard	460					561-4

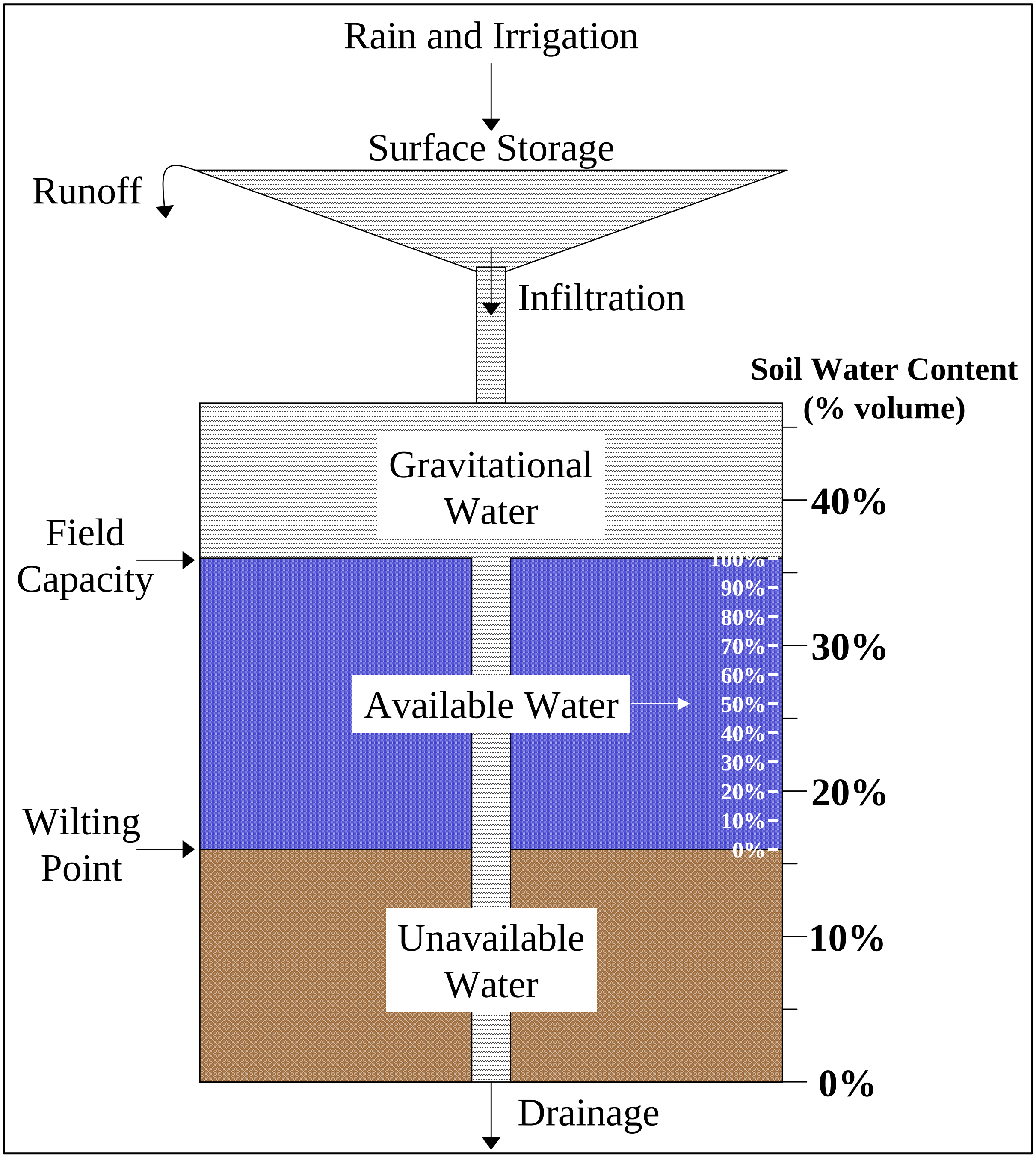

Figure 1. The "bucket model" representation of soil moisture availability of a clay loam soil (Adapted from Hillel, 1998).

An example of a crop for which irrigation can be used to maximize quality is barley. In order to maintain the high protein content required for malt barley, greater amounts of irrigation water are needed than for feed barley. In addition, the final irrigation is usually completed 2-3 weeks earlier for silage barley than for either malt or feed barley (Alberta Agriculture, Food and Rural Development, 2001). The quality of soft white spring wheat can be increased (lowered protein) by maintaining available soil water above 75%, however the resulting moist conditions also increase the potential for lodging (Alberta Agriculture, Food and Rural Development, 2002c).

Irrigating for maximum crop yield and quality is often a matter of correct timing as well as correct amounts. Table 2 gives a very general overview of the irrigation demands of several crops grown in southern Alberta. The first column indicates the crop and the second column indicates the approximate growing season total water demand (rain plus irrigation). The third column gives the lowest allowable in-season level of soil moisture and is given as a percentage (by volume) of the available water (Figure 1). Table 2 also gives an estimate of the effective crop rooting depth, or the depth range from which the crop can extract water. For most crops, a greater proportion of water is extracted from the surface of the soil and an estimate of this is shown (Table 2). Crops are most sensitive to water stress at certain stages of growth, especially during flowering when seed set is determined. One exception to this is sugar beets, which remain sensitive to water stress from just after seeding until two weeks prior to harvest. Table 2 is given as a general summary and more detailed sources for information on the individual crops are available from various Irrigation Branch Agdex publications, which are listed.

SUMMARY

When irrigating to enhance crop yield and quality, it is necessary to have a good understanding of the crop water needs and timing issues, as well as knowledge of the field soil physical characteristics such as available water holding capacity and infiltration rate.

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Irrigation economics – What is an inch of water worth?

Dr. Allan Walburger
University of Lethbridge, Lethbridge, AB

Paper not available.

New irrigated crops of the future

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Irrigated crop production has come a long way since its establishment years when it was employed primarily for drought protection and increasing yields of crops normally grown under dry land conditions. Industry soon developed around irrigated production because it was proven to be a reliable supply of a quality product. Alberta's irrigated crop production is currently in the process of shifting away from maximization yields of traditional crops to maximizing quality of crops that cannot be grown (economically) without irrigation. Throughout Alberta's history of irrigated crop production, whenever a new crop market presents itself, the irrigation industry responded. It started with forage production, developed into vegetables and more recently has moved in support of the livestock industry.

The introduction of new irrigated crops is not as easy as one might think. Just because they grow it in other parts of the country or world does not mean it will succeed here in southern Alberta. A number of factors come into play every time a new crop is suggested for this area.

The first and possibly most important factor in establishing a new crop is the marketability of the crop. Is the market in existence now or do we need to develop the market? If it already exists, who is maintaining the market now and why do we think we can compete with the existing growers. If we need to develop the market, how much product do we need to sustain the market and what might the future expansion levels be?

Second, what are the economics of producing a new crop and how do we get it to the market? Will the end consumer want it in bulk, bagged or processed into a final form?

To be effective in introducing new crops into this region, research and commercialization programs must answer each of these challenges.

In today's world, Alberta farmers grow what they are good at and in the future it will be in our best interest to stay out of markets in which we cannot compete. If we can grow a high quality product better than another country or closer to the market then we will succeed. Growing a crop which requires northern vigor or a special climactic condition will be the areas best suited for new involvement.

Where to From Here?

The Alberta government has developed a "Growth Strategy" for the agricultural sector which looks to the next decade and not surprising to those of us in the irrigation industry, this strategy's success is based on irrigated agriculture taking a lead role. The strategy aims at achieving a $20 billion value-added sector and a $10 billion primary industry sector, with in the next decade. At their peak, these two sectors resulted in GDP values of $9.3 billion in value-added/processing and $8.4 billion in primary production.

Over the past ten years, Alberta has made a significant shift from being an exporter of raw commodities to an exporter of value-added products. Value-added exports now account for 58% of Alberta's total agri-food exports, up from 30% in 1994. The long-term goal of the province is to have the industry continue to grow and five key areas of opportunity have been identified. These areas have been identified as having clear advantages for Alberta and fit within the industry's technological, production and human resource capabilities.

The five areas include; beef, pork, processed meats, industrial products and natural health products. From an irrigated crop perspective, there is potential for investment in four of these areas.

Beef

The strategy in beef includes a 50% increase in feeding and a 20% increase in breeding cows. To meet the needs of these animals, forage and feed/silage production must be increased or purchased from other areas. Figure 1 shows the relationship between cattle on feed and the acres of barley and corn silage (both irrigated crops).

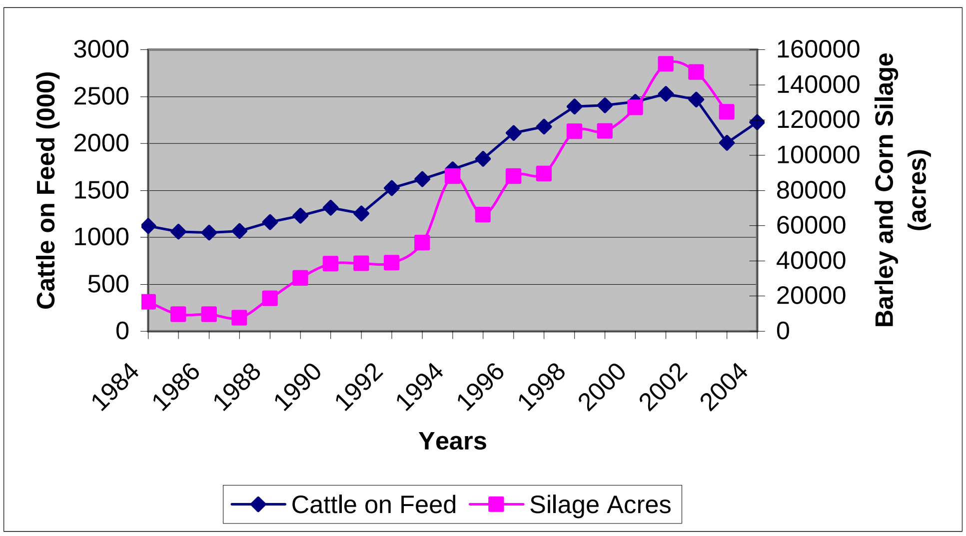

Figure 1. Cattle on feed and silage acres.

In the future, alternative silage crops will be required if we are expecting to grow the nutrition needs of a 50% increase in the feeding industry. What will these crops look like? The crop showing the highest potential at this time is triticale for silage. This crop yields very well under irrigated conditions and if harvested at the correct time, has some superior feed qualities. The second suggestion is double cropping barley or producing three crops in two years by combining both winter and spring crops.

Where will all of these additional animals be located? This may have as big an influence on any new crops/cropping as the need for the feed. In my opinion, they will not be in the special crops corridor but in the west and north fringe of the irrigated areas of Alberta.

Pork

Based on the “Growth Strategy’s” forecast, the population of hogs in the province is anticipated to rise from the current 3.6 million pigs processed to 6.0 million pigs. This increase will also put additional pressure on existing feed supplies. Because of this increase, there is considerable potential for increasing the number of acres of pulses in the province and some of this increase will come in the irrigated areas. Pulses are an excellent crop to grow in rotation and do not require a new line of equipment for seeding or harvest if traditional grains and oil seeds are part of your existing rotation. Price is very important when looking at these crops, as it is difficult to compete with rain fed pulse growers in Manitoba and Saskatchewan. If the hog industry grows to the levels predicted, then an assured supply of feed will be required and the irrigated areas have the ability to produce both high quality and consistent yields which livestock producers need.

Industrial Products

Keep oil at $60.00 US/barrel and the need for fuel alcohol and bio-diesels will be on every producer’s vision of the future. Every year, Canadian farmers grow millions of tonnes of crops that could be used to produce clean, renewable fuels in the form of ethanol and bio-diesel. This huge energy source is equal to an annual supply of 30 million barrels of renewable fuels.

Ethanol can be made from wheat, corn or even straw. Bio-diesel can be produced using canola, soybeans and rendered animal fats. The price of different crops may drive some of the long-term profitability of both bio-diesel and ethanol production. Best estimates have $4.00 canola processed into $0.45/litre diesel (material costs only). If the canola pulp can be fed, then the cost of materials would become more valuable which fits well with the overall growth strategy.

Ontario has already announced an ethanol requirement of 10% by 2010 and Manitoba is considering a requirement of bio-diesel in the next year. The state of Minnesota is requiring 5% of their diesel use to be bio-diesel and will be using soybeans as their oil source. This requirement will equal approximately 7 to 10% of their total soybean crop. How will this impact Alberta’s irrigation industry is still a question but quality and product consistency will likely be a requirement for any new processor and irrigated crop production has an advantage.

If Alberta is to meet its strategy of increasing industrial products, a considerable amount of high starch (low quality grain corn??) and high oil content (soy beans anyone) crops will be required.

Natural Health Products

This sector of agricultural production is very small at the present time with estimates ranging from $40 to $50 million. This could change rapidly and the “Growth Strategy” predicts this sector could grow to $500 million to $1 billion in the next decade.

A growth potential this incredible must be driven by something and we expect two key factors to drive the growth. First is our aging population and a population who has increasing health concerns but also has an acceptance of alternative medicines and are affluent enough to pay for them. The second driver is the move of the middle-age population towards a healthier lifestyle. Weight-loss, low-carb, high fiber and possibly natural/organic foods are the marketing news of the early 21st century.

From an irrigated crop production view, there is considerable potential for new crops to be grown and processed in this market area. The only down side is that many of these new crops will be limited in the acreage grown. One thousand hectares of a particular herb may flood the market, so producers will need to be vigilant in knowing the market place and the crop potential.

Exported Commodities/Products

If the irrigation industry is to succeed in the export market, it must be based on high quality and "Canada Branded" products. We must continue to look at who our competitors are and how they produce the raw commodity. We cannot compete against rain fed crops. Even in Alberta, the irrigation producer's ability to compete against the canola growers from central/northern Alberta must be questioned. There will always be room for some of these crops due to quality and consistency of product volumes but a good year there means a poor one here.

Trading Partners

The top five markets for Alberta's agri-food products in 2003 were the United States, Japan, Mexico, Taiwan and China. Exports to these markets were worth $4.0 billion, accounting for about 80% of Alberta's total agri-food exports.

Among the top five markets, Taiwan and China reported increases over the previous year. If we can find and produce a commodity wanted by these countries, the possibilities would be enormous.

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