IRRIGATED CROP PRODUCTION UPDATE 2008

January 22, 2008

Lethbridge Lodge Hotel
Lethbridge, Alberta

Irrigated Crop Production Update

2008

Conference proceedings

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Irrigated Crop Production Update 2008

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IRRIGATED CROP ROTATION RESEARCH

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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 irrigated rotation study was initiated in 2000 at Vauxhall, AB 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 were to devise crop sequences and tillage systems for irrigated land that: (1) optimized crop response; (2) reduced soil erosion, enhanced soil quality and promoted long-term sustainability; and (3) minimized weed, insect and disease pressures.

EXPERIMENTAL TREATMENTS

Crop rotations (Table 1) were established in spring 2000 at Vauxhall, AB.

Table 1. Irrigated crop rotation details, Vauxhall, AB.

Rotation length, years	Crop sequence	Management
1	W	Continuous wheat
3	(P-B-W)c	Conventional
3	(P-B-W)s	Sustainable
4	(W-SB-B-P)c	Conventional
4	(W-SB-B-P)s	Sustainable
5	P-W-SB-W-B	Sustainable (cereal breaks)
6	O(t)-T-T-SB-B-P	Sustainable (forage break)

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.

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

Cumulative Effects on Crop Yield

Complete results for the 2007 growing season were not available at the time of writing. Therefore, the following results are from the 2000-06 period only.

In order to look at cumulative rotational and management effects on crop yield, parameters were expressed as average values for the first two years (2000, 2001), the first three years (2000, 2001, 2002), the first four years (2000, 2001, 2002, 2003), the first five years (2000, 2001, 2002, 2003, 2004) and the first six years (2000, 2001, 2002, 2003, 2004, 2005) and the first seven years (2000, 2001, 2002, 2003, 2004, 2005, 2006). This integrates the effects over time and shows if, when and where trends begin to emerge. With these comparisons of average values it has to be borne in mind that the cropping history will not be fully manifested, especially for the longest rotations in the early years. As yields are averaged over more years the comparisons become more robust.

Beans: Table 1 shows that significant rotational effects on average bean yields occurred in first three years, e.g. 4 yr conventional beans averaged 2339 kg ha^{-1} which was significantly higher than the 3 yr sustainable and the 5 yr and 6 yr rotations (1525-1929 kg ha^{-1}). After that, rotational effects were non-significant as the sustainable rotations (narrow row) ‘caught up’ with the conventional ones (wide row). This is demonstrated by the lack of significance between management systems (conventional vs. sustainable) when averaged over 6 and 7 years (P = 0.88, 0.47) compared to 2, 3 and 4 years (P <0.01).

Potatoes: For potato yield (Table 2), there was no effect of rotation on average yield in the first three years of the study. However, when averaged over >4 years, significant differences became apparent. The 3 yr sustainable rotation was 15% higher yielding than its conventional counterpart when averaged over 7 yr. Also it took six years for average yields on the sustainable rotations (43.2 Mg ha^{-1}) to be significantly higher (by 7%) than those on the conventional rotations (40.5 Mg ha^{-1}). This effect was maintained when averaged over the first 7 yr (P = 0.02).

Table 1. Rotation effect on average bean yields at Vauxhall, 2000-06.

	kg ha^{-1}					
	First 2 yr	First 3 yr	First 4 yr	First 5 yr	First 6 yr	First 7 yr
			Rotation			
3 Yr Conv.	2386ab†	2083ab	2160	2077	2025	2054ab
3 Yr Sust.	2148abc	1741bc	1833	1867	2068	2031ab
4 Yr Conv.	2627a	2339a	2268	2253	2178	2231a
4 Yr Sust.	2230abc	1995ab	2010	2098	2216	2207a
5 Yr	1734c	1525c	1834	1881	1876	1855b
6 Yr	2042bc	1929b	1992	2065	2306	2224a
$LSD_{0.05}$	0.04*	0.008**	0.13^{ns}	0.16^{ns}	0.06^{ns}	0.01*
			Overall Soil Management			
Conv.	2507a	2211a	2214a	2168	2102	2142
Sust.	2039b	1798b	1917b	1978	2116	2079
$LSD_{0.05}$	0.007**	0.004**	0.008**	0.06^{ns}	0.88^{ns}	0.47^{ns}

†Means followed by the same letter are not significantly different from each other according to Least Significant Difference ($LSD_{0.05}$).

Table 2**.** Rotation effect on average potato yields (marketable + oversize) at Vauxhall, 2000-06.

	Mg ha^{-1}					
	First 2 yr	First 3 yr	First 4 yr	First 5 yr	First 6 yr	First 7 yr
			Rotation			
3 Yr Conv.	44.8	37.3	39.6d†	40.3b	38.5b	38.3b
3 Yr Sust.	45.6	42.3	44.9a	45.8a	44.4a	43.9a
4 Yr Conv.	48.4	42.0	43.3abc	43.4ab	42.5a	42.5a
4 Yr Sust.	43.5	36.6	39.9cd	41.0b	41.5ab	41.7a
5 Yr	47.7	42.7	43.9ab	45.5a	44.6a	44.2a
6 Yr	44.8	37.1	40.8bcd	41.9ab	42.2a	42.8a
$LSD_{0.05}$	0.60^{ns}	0.07^{ns}	0.03*	0.04*	0.02*	0.01*
			Overall Soil Management			
Conv.	46.6	39.6	41.5	41.9	40.5b	40.4b
Sust.	45.4	39.7	42.4	43.6	43.2a	43.1a
$LSD_{0.05}$	0.52^{ns}	0.98^{ns}	0.50^{ns}	0.23^{ns}	0.03*	0.02*

†Means followed by the same letter are not significantly different from each other according to Least Significant Difference ($LSD_{0.05}$).

Sugar Beet: Average extractable sugar yields showed no significant effects due to rotation or overall management (Table 3) and as such sugar beets were the least responsive of the four main crops in the study (beans, potatoes, sugar beet, wheat). Numerically however, the 4 yr conventional rotation was lower yielding than the other three sustainable rotations when averaged over all time periods (first 2 to first 7 years). Averaged over the first five years, extractable sugar on the conventional rotation (9071 kg ha^{-1}) was almost significantly lower (P = 0.06) than the sustainable rotations (9574 kg

ha^{-1}) a difference of 5.5%. However, this trend was not stronger when averaged over 7 yr (P = 0.13).

Table 3. Rotation effect on average extractable sugar yields at Vauxhall, 2000-06.

	kg ha^{-1}					
	First 2 yr	First 3 yr	First 4 yr	First 5 yr	First 6 yr	First 7 yr
			Rotation			
4 Yr Conv.	9270	8134	8545	9071	9053	9223
4 Yr Sust.	9787	8960	9135	9721	9476	9584
5 Yr	9796	8519	8868	9621	9488	9638
6 Yr	9324	8297	8762	9380	9170	9346
$LSD_{0.05}$	0.42^{ns}	0.34^{ns}	0.49^{ns}	0.21^{ns}	0.31^{ns}	0.28^{ns}
			Overall Soil Management			
Conv.	9270	8134	8545	9071	9053	9223
Sust.	9636	8592	8922	9574	9378	9523
$LSD_{0.05}$	0.28^{ns}	0.24^{ns}	0.22^{ns}	0.06^{ns}	0.16^{ns}	0.13^{ns}

Wheat: Average wheat yields (Table 4) were affected by rotation when averaged over all periods of the study. This was mainly due to the low yields on the continuous wheat (Treatment 1). Averaged over the first 6 years, the continuous wheat yielded 68-76% of all the other rotations. Also, the first wheat phase in the 5 yr rotation, i.e. after potatoes, had a significantly lower average yield (5.14 Mg ha^{-1}) than the 3 year conventional rotation (5.66 Mg ha^{-1}). This effect continued when averaged over 7 years.

Table 4. Rotation effect on average wheat yield at Vauxhall, 2000-06.

	Mg ha^{-1}					
	First 2 yr	First 3 yr	First 4 yr	First 5 yr	First 6 yr	First 7 yr
			Rotation			
Cont.	5.10b†	4.23b	3.75c	4.05b	3.89c	4.06c
3 Yr Conv.	6.82a	5.67a	5.58ab	5.88a	5.66a	5.78a
3 Yr Sust.	6.56a	5.70a	5.65a	5.85a	5.55ab	5.64ab
4 Yr Conv.	6.56a	5.67a	5.49ab	5.77a	5.43ab	5.57ab
4 Yr Sust.	6.30a	5.50a	5.10ab	5.47a	5.20ab	5.32ab
5 Yr 1st	6.47a	5.35a	5.06b	5.49a	5.14b	5.25b
5 Yr 2nd	6.88a	5.78a	5.28ab	5.51a	5.55ab	5.63ab
$LSD_{0.05}$	0.003**	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***
			Overall Soil Management			
Conv.‡	6.69	5.67	5.54	5.82	5.55	5.67
Sust.	6.55	5.58	5.27	5.58	5.36	5.46
$LSD_{0.05}$	0.56^{ns}	0.61^{ns}	0.16^{ns}	0.11^{ns}	0.23^{ns}	0.14^{ns}

†Means followed by the same letter are not significantly different from each other according to Least Significant Difference ($LSD_{0.05}$). ‡Continuous wheat omitted from conventional treatments.

Overall management had no significant effect on wheat yields although there was a non-significant trend (P = 0.11 to 0.23) of conventional yields being higher than sustainable yields when averaged over the first 4 years, first 5 year and first 6 years or first 7 years (Table 26). It should be mentioned that continuous wheat was not included as a conventional treatment in this comparison.

OTHER MEASUREMENTS

Weed and insect populations, agronomic, quality and disease characteristics, , soil microbiological properties, soil fertility and soil quality, soil water, and residue cover measurements are also taken on the plots.

SUMMARY

This study continues to build after eight years of cropping. In those eight years we have seen one of the driest (2001) and the extreme wettest (2002 and 2005) growing seasons at Vauxhall. This emphasizes the need for long-term rotational experiments such as these to capture a broad range of climatic variables. This only makes the results and associated conclusions more robust.

A trend of better performance in the sustainable vs. conventional rotational practices is starting to emerge especially in potato yield patterns 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 past and present funding support. Dermot Lynch, Henning Mündel, and Henry Huang (retired AAFC staff) and Jennifer Nitschelm (formerly Rogers Sugar) contributed during the early years of the study. Ron Gregus, Dale Reynolds, Monty Whitmore, Ron Feldbusch, Jim Sukeroff, John Laturnus, Doug Friebel, Scott Erickson, Mike Balint, Harvey Dyck, Cathy Daniels and John Braun provided technical and field help.

PRINCIPLES FOR SOUTHERN ALBERTA IRRIGATED CROP ROTATIONS

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Crop rotations for irrigation have developed in response to market opportunities that enable farmers to take advantage of the extra water available to improve farm profitability. The following is a brief description of a few of the principles that guide good crop rotation decisions for irrigation in southern Alberta.

Crop rotation principles

Good rotation is a time-tested way to enhance soil quality and crop productivity while keeping input costs in line. Having a more diverse mix of crops help spread the workload and price risks associated with a crop monoculture. Crop rotation describes the sequence of crops grown within a particular field. Individual farmers may have several rotations, depending on soil and field characteristics, irrigation, landlord demands or distances from the main farm area.

Good dryland rotations are often similar within a region because farms have developed with similar soil, climate and pest issues to meet food, feed, fibre – and now fuel market opportunities. Not so with irrigated land where we see many different crop types and rotations because we have eliminated some of the climate risk (drought). For irrigated cropland, technology often substitutes for good rotation practices to manage pest or soil related problems (for example, fungicides or drainage). Crop choice is often driven more by a high revenue opportunity like a potato contract or forage needs with cattle.

Rotations should include as much crop diversity as possible to manage market risk, spread workloads and culturally control pests (diseases, weeds and insects). This is usually true for irrigation with the exception of a few unique situations like cereal silage for cattle feeding operations.

Irrigated rotations will always be more water use intensive than dryland to take advantage of the land and capital investment for yield and profitability. Intensity not only relates to the amount of crop water use but also the depth of water use, given that some moisture (and other nutrient) will escape shallow rooted crop types. Irrigated crops are therefore usually full season with high water use but this is balanced by the need to spread workloads at seeding and harvest, as well as issues around water allocation. Forages are the most intensive water users and occupy a significant portion of irrigated acreage. Peas, dry beans and barley silage are examples of crops that have a low relative demand for irrigation water (low water use intensity).

Water use efficiency (WUE) is also important for irrigated crops but is impacted more by cropping system than rotation. WUE relates to the amount of grain, forage, protein, oil, sugar, etc. produced per unit of water (eg. kg/ha/mm water). Rotation has an influence because healthy, vigorous crops (influenced by crop sequence) are more water use efficient. Crop choice can also have an effect. For example, winter crops are more water efficient because they develop during the cooler fall, spring with less needed for evapo-transpiration. Warm season (C-4) crops like corn are also inherently water efficient because of plant physiology.

Rotation will impact on nutrient cycling and soil quality because crops differ in things like residue production (above and below ground), rooting type (tap versus fibrous versus tuber) and plant residue decomposition rates following harvest. Crops with less or easily decomposable residue should therefore be balanced with higher residue crops to reduce erosion risks and maintain soil organic matter. Residues not only protect from erosion but also fuel important biological soil processes that improve water infiltration and nutrient cycling. Legume crop residues have a lower carbon to nitrogen ratio and tend to therefore shed more nitrogen to the following crop. This extra nutrient is tied up as plant proteins and therefore doesn't show up until decomposition processes have kicked in through late fall and spring.

Following crop yield impacts

For rotations, yield impacts on following crops have been observed by scientists, agronomists and farmers, but the reasons for yield increase or reductions are not always clear. Disease, soil quality and nutrient cycling are thought to be the most important for irrigation with soil moisture more critical for dryland cropping systems. Most crop diseases decline rapidly in the absence of a suitable host. Some crops also have a bio-sanitizing effect for root diseases in the following crop, for example cereals grown after canola or peas, although we're not sure why (could be reduced disease inoculum or beneficial effects of soil microorganisms). Yield increases following forages is another example that can be attributed to the cumulative effects of increased soil nutrient supply (from accumulated organic matter), better soil structure and disease reduction. Suffice to say that anything that improves germination, emergence and early season vigor will increase crop yield potential.

Disease and soil issues are the most likely reasons for poorer yields following some crop types, especially during the crop establishment phase. Allelopathic effects from previous crop residues can inhibit germination or slow early crop development but this is rare and often confused with residue related nutrient issues (ie. nutrient immobilization). Cooler, wetter soils on heavy residue cereal stubble can delay early crop development for all crops but may be a more serious issue for a heat-loving crop like dry bean. Frost risk may also be higher on fields with heavy residue cover. Conversely, low residue fields can dry out, delaying emergence until irrigation water is available. Bare soils can

also heat up to the point where leaves are scalded and plant crowns are injured during early development for heat sensitive crops like cereals, peas or canola.

Managing pests with rotation

Rotation is used to manage tough to control or potentially costly diseases for a crop like potato that impacts both yield and quality with several hundred or even thousands of dollars per acre at risk. Processing companies obviously play an important role by only contracting if minimum rotation intervals are maintained to ensure product quality. Fungicides rather than rotation are used when crop choices are limited by farm operation demands, for example beef silage production. In this case rotating cereal types like barley, triticale and corn is effective. Rotating barley varieties can also be effective because of differences in susceptibility to various strains of leaf disease pathogen.

Weed issues can also be more effectively managed with good rotations because grassy weeds are more easily and cheaply controlled in broadleaf crops and vice versa. Weed resistance development can also be management by using different herbicide modes of action with different crop types (or control by tillage with row crops).

Maintaining soil quality with intensively tilled, low residue crops

Tillage intensity, especially during the land preparation phase has declined for potato, sugar beet and bean in recent years. Emerging practices like zone tillage and cover crops may one day further reduce erosion and improve soil quality for high-risk situations. Solid seeding of dry beans may also become more widespread as suitable upright varieties are releases for the various bean market classes. Post harvest cereal cover crop or sequencing to winter wheat after bean and potato are becoming more common, but few potato fields are harvested in time to allow sufficient cover crop growth to protect from wind erosion. Most potato, bean and sugar beet fields are fall chiseled or ridged to help prevent wind erosion and some of the potato fields on sandier soil types have cereal straw spread to stabilize soil during the winter-spring period.

Several potato farmers routinely apply composted manure to maintain or improve soil quality and productivity. Compost is seldom used prior to sugar beets because of the need to carefully manage nitrogen supply for optimum yield and quality.

Growing a cereal for grain before and after sugar beets or potato, with all of the straw left in the field is a recommended practice to help maintain soil quality although this is not often practiced. Canola is another alternative for rotations without sugar beet (canola is a concern since it can serve as a host for the sugar beet cyst nematode). Growing a cereal once in a 3 or 4 year rotation such as potato-bean-wheat or potato-bean-sugar beet-wheat is common practice and is being evaluated in terms of soil quality and production risks at the AAFC Irrigated Cropping Systems Study at Vauxhall (presented earlier by Dr. Frank Larney).

Rotational benefits from perennial forages

Including forages in a crop sequence is one of the best ways to build soil quality, capture deep leached nutrients and spread workloads. Timothy for export and alfalfa or alfalfa-grass for livestock feed are important irrigated crops and can be sequenced with low residue annual crops to maintain or build soil quality in rotations. Alfalfa fixes nitrogen and has a deep tap-root capable of improving internal soil drainage and extracting deep-leached moisture and nutrient. Timothy is a more shallow, but highly fibrous rooted bunch grass that can rapidly improve soil organic matter and tilth in rotations.

SUMMARY

Rotations for irrigation are complex and usually have a high level of crop diversity and water use intensity. Yield and quality losses from pests, mainly soil borne diseases, are managed with good rotations. Benefits to following crops can accrue from things like reduced disease inoculum, improved soil or enhanced nutrient levels. Impacts are most often seen during early crop development with lasting effects on yield and quality. Practices are continuing to evolve to prevent erosion and maintain soil quality with low residue crops in rotation. These include things like compost application, cover crops, solid seeded beans and zone tillage. Including perennial forages like timothy and alfalfa in sequence with annual crops is fairly common on irrigation and can dramatically improve soil quality and yields.

ZONE TILLAGE OF SUGAR BEETS (2004 – 2007)

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INTRODUCTION

In southern Alberta, reduced tillage in sugar beets has contributed to improved control of wind erosion. Recently, a sugar beet grower in the Taber area developed and used a 24-row zone tillage implement to further manage crop residue and erosion. In fall 2004, the Ag Tech Centre in Lethbridge, Alberta built a 6-row research zone tillage implement with guidance and financial support from the Alberta Sugar Beet Growers/ Rogers Sugar Ltd research department and Alberta Agriculture and Food. The 6- and 24-row units operate on the same principle, tilling a narrow strip where sugar beets will be seeded while leaving the inter-row area undisturbed.

Early season soil temperature and sugar beet production were evaluated for this zone tillage system in comparison with conventional tillage over a 4 year period. In 2004 and 2005 soil temperatures and speed of sugar beet emergence were evaluated in a commercial field where conventional tillage was compared to tillage using the 24-row zone tillage implement. In 2005 through 2007 small plot experiments that evaluated soil temperature, speed of sugar beet emergence and sugar beet production were conducted using the 6-row research zone tillage implement.

METHODS

Commercial field experiments had 2 treatments (zone and conventional tillage) in a randomized complete block design with 8 replications in 2004 and in a strip trial that utilized a paired T-test with 4 replications for analysis in 2005. All small plot experiments were identical and used a randomized complete block factorial design with 6 replications and 4 treatments. This summary will only discuss the conventional versus zone tillage comparisons in the small plot trials, although other treatments were present.

All experiments followed a cereal crop and all straw was left on the field where the commercial 24-row implement was evaluated. Straw was baled and removed prior to conducting the small plot experiments. In the small plot experiments, conventional tilled

plots were worked 2 or more times in fall and once in spring with the objective of reducing the amount of surface residue to below 25%. The rate of fertilizer applied was identical in zone and conventionally tilled areas in all tests.
Hobo H8 4-channel data loggers were installed to assess soil temperatures at hourly intervals. Below-ground logger sensors were inserted at 5 cm depths. Below-ground sensors were located in-row and halfway between seed rows in zone tilled treatments, while sensors were only located in-row in conventional treatments. In the 2006 and 2007 small plot trials above-ground logger sensors were also installed in the seed rows 2.5 cm above soil level.

Sugar beet stand was counted in all treatments at intervals between emergence and the 4-leaf stage. Measurements to quantify percent ground cover from stubble were conducted in each treatment of the small plot trials using the line-transect method. Plant canopy vigour was rated on a 1-9 scale between the 4 and 8-leaf stage of sugar beet development for all small plot trials, with higher numbers indicating better vigour.

RESULTS

A summary of speed of emergence results for all trials are presented in Table 1. The speed of emergence and final established plant stand were not significantly different for 20 of 25 plant counts conducted for zone and conventional tillage treatments over a 4 year period. In 4 of 5 cases where significant differences occurred, stands were higher in conventional treatments.

In the commercial field trial in 2004, conventional and zone tillage operations were conducted in the spring prior to seeding, with no significant precipitation occurring until 14 days after seeding. In these conditions zone tillage treatments had significantly greater emergence 21 days after seeding; however, final stand was similar to conventional tillage. In the commercial field trial in 2005, zone tillage was conducted in the fall while conventional strips were worked in the spring. Significant precipitation was received the day after conventional tillage operations were performed in this test. The speed of sugar beet emergence in the 2005 commercial field was faster with conventional tillage than with zone tillage, although final plant count was not significantly different. In the 2006 small plot trial the initial sugar beet emergence count was significantly higher in conventional tillage treatments than in zone tillage treatments; however, counts for the remainder of the emergence period were not significantly different.

The final established stand count was significantly higher for conventional tillage than for zone tillage in 1 of the 5 trials conducted. The established stand was significantly higher for conventional tillage in the 2005 small plot trial; however, the actual stand achieved for zone tillage plots was still considered in the optimum range for sugar beet production.

Results over 4 years indicate that in most cases it was possible to achieve emergence stands with zone tillage that were comparable to conventional tillage stands.

Table 1. Summary of speed of emergence results for zone tillage trials (2004 – 2007).

Treatment		Sugar beet stand (plants/100ft of row)				
2004 (Commercial Field)	**DAP[a]**	**21**	**24**	**26**	**39**	**70**
Conventional tillage		32	79	120	147	143
Zone tillage		63	87	116	133	137
LSD (.05)		*23*	*NS*	*NS*	*NS*	*NS*
2005 (Commercial Field)	**DAP**	**14**	**17**	**19**	**21**	**27**
Conventional tillage		26	151	162	172	195
Zone tillage		3	55	100	141	186
Significance (5% level)		*NS*	*	*	*NS*	*NS*
2005 (Small Plot Trial)	**DAP**	**11**	**14**	**17**	**21**	**29**
Conventional tillage		0	94	118	138	172
Zone tillage		0	90	117	131	158
LSD (.05)		*NS*	*NS*	*NS*	*NS*	*12*
2006 (Small Plot Trial)	**DAP**	**12**	**14**	**17**	**20**	**33**
Conventional tillage		21	90	117	126	130
Zone tillage		10	79	114	125	130
LSD (.05)		*8*	*NS*	*NS*	*NS*	*NS*
2007 (Small Plot Trial)	**DAP**	**9**	**12**	**14**	**16**	**33**
Conventional tillage		1	80	143	151	156
Zone tillage		2	77	140	143	152
LSD (.05)		*NS*	*NS*	*NS*	*NS*	*NS*

[a] DAP = Days after planting

Average hourly early season soil temperatures are reported in Table 2. In-row soil temperature differences were small when zone and conventional tillage were compared. In the 5 trials conducted, zone tillage resulted in in-row soil temperatures that averaged 0.4^{o}C lower than temperatures measured in conventional residue. In-row soil temperature was either the same or slightly lower for zone tillage than for conventional tillage in individual experiments.

The undisturbed area between zone tilled strips had a greater accumulation of cereal residue than areas where tillage was conducted and this resulted in somewhat lower

temperatures in the inter-row area. The inter-row area was 0.7°C lower in temperature than the zone tilled strips and 1.1°C lower than conventional tillage when averaged over the 5 trials.

Table 2. Summary of early season below ground soil temperature (°C) for zone tillage trials (2004–2007).

Average hourly soil temperature (5 cm depth)	Zone tilled		Conventional
	Between-row	In-row	Tillage
2004 (Commercial Field) – April 29 to May 4	10.9	11.9	13.0
2005 (Commercial Field) – April 24 to May 12	8.2	8.9	9.4
2005 (Small Plot Trial) – April 8 to May 11	8.3	8.6	8.8
2006 (Small Plot Trial) – April 19 to May 11	10.2	10.9	10.9
2007 (Small Plot Trial) – April 17 to May 15	10.5	11.0	11.4
Average hourly temperature for all tests	*9.6*	*10.3*	*10.7*

Differences in in-row above ground temperatures for zone and conventional tillage were also assessed in 2 of the small plot trials that were conducted (data not shown). Average hourly above ground temperatures were 0.3°C higher for zone tillage than for conventional tillage. This slight increase in average temperature was a result of a 1.4 °C increase in the average daily maximum temperature for zone tillage treatments compared to conventional tillage. Although differences were small, minimum above ground temperatures for zone tillage were 0.4 °C colder than for conventional tillage. Minimum values were also 0.4 °C colder for zone tillage on days when subzero temperatures occurred at 2.5 cm above the soil surface. This might indicate that zone tilled sugar beets could be slightly more susceptible to early season frost. In general, the temperature data suggests that zone tillage did not have a substantial impact on above or below ground early season temperature compared to a conventional system.

Sugar beet production results are summarized in Table 3. Extractable sugar per acre was not significantly different between zone and conventional tillage in any of the individual small plot trials, although conventional treatments were always slightly higher. In 1 of 3 trials extractable sugar per tonne was significantly higher for conventional tillage. Beet yield was also significantly higher for conventional tillage in 1 of 3 trials. In all small plot trials significantly greater plant vigour was observed in June for conventional tillage treatments. These vigour differences disappeared by mid-summer.

In the 2007 experiment soil nitrate levels and nitrogen supply rates were assessed to try and explain the vigour differences observed. In-row nitrate nitrogen levels to 60 cm

depth on June 20 were 24 ppm for conventional tillage and 83 ppm for zone tillage. Nitrogen supply rates were measured using PRS^{TM} probes (Western Ag Innovations, Saskatoon, SK) inserted for 13 days starting on June 20. The total nitrogen supply rate (µg/10cm^{-2}) was 211 for conventional tillage and 267 for zone tillage. Soil samples and PRS^{TM} probes suggested that nitrogen availability was not a contributing factor to the lower vigour observed in the zone tillage treatments in June.

Ground cover measurements in the small plot trials show the level of residue for zone tillage was consistent over years and was significantly higher than residue levels in conventional treatments. Conventional treatments were tilled less aggressively in 2007 than in the previous 2 years.

Table 3. Yield and quality results for the small plot zone tillage trials – 2007.

Treatment	Extractable Sugar		Sugar	Molasses Loss	Beet Yield	Vigour (June)	Ground Cover
	kg/acre	kg/t	%	%	t/acre	1-9	(%)
2005							
Conventional tillage	4559	151.2	16.66	1.54	30.22	7.7	13
Zone tillage	4300	157.3	17.24	1.50	27.35	7.1	37
LSD (.05)	*NS*	*NS*	*NS*	*NS*	*1.59*	*0.4*	*6*
2006							
Conventional tillage	5434	173.1	18.74	1.44	31.41	7.5	11
Zone tillage	5156	169.9	18.48	1.49	30.37	6.7	36
LSD (.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*0.3*	*5*
2007							
Conventional tillage	3656	149.1	16.67	1.76	24.47	7.0	23
Zone tillage	3556	142.5	16.13	1.89	24.96	6.7	36
LSD (.05)	*NS*	*4.7*	*0.40*	*NS*	*NS*	*0.2*	*5*

SUMMARY

Results over 4 years indicate that in most cases it was possible to achieve emergence stands with zone tillage that were comparable to conventional tillage stands. Temperature data suggests that zone tillage did not have a substantial impact on above or below ground in-row early season temperature compared to a conventional system. Visual evaluations of plant vigour in June indicated the leaf canopy was more robust for conventionally tilled treatments and there was also a trend for slightly higher extractable sugar per acre for these treatments. The zone tillage system studied in these trials

appears to be a viable option for consideration by Alberta sugar beet producers interested in improving control of wind erosion. Further investigation is continuing through larger scale strip trials being conducted by Alberta Agriculture and Food at the CACDI site in Lethbridge, Alberta.

CONSERVATION SYSTEM RESEARCH FOR DRY BEANS

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INTRODUCTION

Production of pulse crops has steadily increased over the last two decades on the Canadian prairies because they often provide greater economic return compared with cereals. Field pea and lentil account for much of the increase but dry bean hectares also have increased four-fold (currently about 125,000 ha). Farmers have widely adopted zero tillage practices for production of field pea and lentil because of greater 'snow trapping', increased water infiltration into soil, and reduced evaporative losses from the soil surface that results in greater amounts of available soil water needed for viable pulse crop production in this semi-arid environment.

Despite widespread adoption of zero tillage for some pulses, dry bean in western Canada is largely produced under conventional tillage. The recent development of dry bean cultivars with an upright, determinate growth habit has made zero tillage production more feasible. Previous research has shown mixed results regarding zero-till dry bean production. A Michigan study found that dry bean yield following corn was sometimes reduced with zero tillage but that the economic returns could be higher due to reduced production costs. In contrast, dry bean yield was similar with conventional and zero tillage systems in Ontario.

Even if zero tillage is found to be suitable for dry bean production, it offers few benefits when dry bean is grown after low residue crops such as potato or sugar beet. In this situation cover crops may have a good agronomic fit in terms of providing ground cover to protect the soil from erosion, reducing wind injury to bean seedlings, enhancing pest management, and potentially improving yield of dry bean. No research has been conducted on cover crops and dry bean in western Canada.

Multi-year field studies were conducted to determine 1) the response of dry bean grown in various crop stubbles under conventional and zero tillage and 2) the agronomic merits of various fall- and spring-seeded cereal cover crops in dry bean production systems on the Canadian prairies.

BODY

Zero Tillage

Dry bean emergence was delayed in 1 of 6 site-years with zero tillage compared with conventional tillage but maturity date was not affected (data not shown).
Dry bean density was never lower with zero tillage compared with conventional tillage and was higher in a few instances (Lethbridge 2003 and Lacombe 2004) (Table 1).

Table 1. Dry bean density response to tillage intensity averaged over all previous crop stubbles (wheat, barley, canola and flax).

	Conventional tillage	Zero tillage
	plants m^{-2}	
Lethbridge		
2001	33	31
2003	37	43
2004	36	35
Lacombe		
2003	38	39
2004	35	42
2005	41	39

There were no differences in insect or disease infestations between the two tillage treatments. Weed densities were slightly greater with zero tillage compared with conventional tillage but were well controlled with in-crop applications of Poast (sethoxydim) and Basagran (bentazon).

Flax was the only previous crop to negatively affect dry bean yield as volunteer flax was not adequately controlled with Basagran (Table 2). Over all previous crop stubbles and years, dry bean yield was similar in both tillage systems.

Table 2. Effect of previous crop and tillage intensity on dry bean yield at Lethbridge.

Treatment	Previous crop	Tillage intensity	2001[b]	2003	2004
			kg ha^{-1}		
1	Wheat	CT[a]	1100	3530	2650
2	Wheat	ZT	1220	3220	2510
3	Barley	CT	910	3530	3060
4	Barley	ZT	1460	3280	2930
5	Canola	CT	1250	2280	2750
6	Canola	ZT	1100	2870	3030
7	Flax	CT	220	2100	1370
8	Flax	ZT	130	2740	980

[a]CT = conventional tillage; ZT = zero tillage.

Cover Crops
Treatments included various fall-seeded and spring-seeded cereal cover crops with and without in-crop herbicides in dry bean. Main plot treatments included fall-seeded winter rye, barley, oat, and spring rye; spring-seeded barley, oat, and spring rye; and a no-cover crop control. Subplot treatments consisted of in-crop Poast plus Basagran or a no-herbicide control.

Fall-seeded cover crops were often superior to spring-seeded cover crops in terms of providing sufficient ground cover to reduce the risk of soil erosion (Table 3). Winter rye provided the most surface residues in all years.

Table 3. Cover crop residue on the soil surface prior to seeding dry bean.

	Biomass (g m^{-2})		
Cover crop	2003	2004	2005
Fall-seeded winter rye	552	632	794
Fall-seeded barley	132	99	38
Fall-seeded oat	117	107	40
Fall-seeded spring rye	148	113	114
Spring-seeded barley	69	56	19
Spring-seeded oat	40	57	28
Spring-seeded spring rye	47	42	23

Fall-seeded cover crops also reduced weed emergence and biomass production to a greater extent than spring-seeded cover crops (data not shown). Among the fall-seeded cover crops, winter rye gave the greatest reduction in weed biomass in the absence of herbicides in all years. When in-crop Poast and Basagran were applied, weed biomass was still lower with the winter rye cover crop than all other cover crop treatments in 2 of 3 years.

Dry bean density was not affected by any of the cover crops but fall-seeded cover crops delayed emergence by up to 5 days and delayed maturity by up to 4 days (data not shown). Cover crop effects on dry bean yield were most evident in the absence of in-crop herbicides, where fall-seeded cover crops increased dry bean yield by 20 to 90% (Table 4). Cover crops also increased dry bean yield in 2 of 3 years when in-crop herbicides were used but yield increases were much smaller, ranging from 5 to 13%. These yield increases occurred with fall-seed cover crops that aided in weed management but also with spring-seeded cover crops where weed suppression was not evident, suggesting that cover crops provided additional benefits beyond weed management.

Table 4. Dry bean yield response to the cover crop and in-crop herbicide treatments.

	Dry bean yield (kg ha^{-1})					
	No herbicide			Herbicide		
Cover crop	2003	2004	2005	2003	2004	2005
No-cover crop control	1640	1120	440	3380	2890	3310
Fall-seeded winter rye	2330	1510	840	3730	3080	3280
Fall-seeded barley	1980	1270	630	3560	3080	3240
Fall-seeded oat	1960	1360	650	3610	3130	3250
Fall-seeded spring rye	2140	1290	570	3830	3040	3400
Spring-seeded barley	1800	1140	430	3580	2940	3060
Spring-seeded oat	1910	1260	480	3520	3230	3090
Spring-seeded spring rye	1870	1190	500	3390	3200	3050

CONCLUSIONS

Dry bean can be successfully grown in zero tillage systems in western Canada. Dry bean stand establishment, pest management, maturity date, and yield were not compromised in a zero-till compared with a conventional-till production system. Growers should be cautioned about zero-till dry beans following flax as few in-crop herbicide options exist for volunteer flax control.

Cover crops will likely be most beneficial when dry bean follows crops that leave little plant residue on the soil surface (e.g., potato or sugar beet). Fall-seeded cover crops were superior to spring-seeded cover crops. Winter rye provided the greatest ground cover and caused the greatest weed suppression.

Dry bean yield in the presence of in-crop herbicides was increased 5 to 13% by including cover crops in the production system in 2 of 3 years. Additional cover crop benefits in our windy, semi-arid environment may be reduced wind injury to dry bean seedlings, increased infiltration of rainfall and irrigation water, increased soil water conservation, and improved soil nutrient dynamics.

A potential disadvantage of using cover crops is delayed dry bean maturity. Winter rye delayed maturity by 3 to 4 days in two of three years. Additionally, fall-seeded barley and oat delayed dry bean maturity by 2 days in one year. Dry bean was not affected by fall frosts in our study but any delay in maturity is a concern in the short season environment of the Canadian prairies. Seeding earlier in the spring may be a partial solution but it would need to be considered against the possibility of dry bean injury from late spring frost events.

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CHALLENGES IN PREDICTING IRRIGATED CROP FERTILIZER RESPONSE – DYNAMICS OF SOIL NUTRIENT RELEASE

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INTRODUCTION

How much fertilizer should you apply to irrigated crops? If the answer is "The same amount as last year" that may or may not be right answer. Irrigation producers need to ensure their fertilizer practices are both efficient and profitable. Alberta Agriculture and Food has committed considerable resources to research for the development of fertilizer recommendations based upon soil test levels for a number of irrigated crops.

To understand irrigated crop response to fertilizers, producers must also understand the dynamics of soil nutrients and availability in irrigated soils. The purpose of this paper is to explain some of the dynamics of nutrients in irrigated soils to assist producers in making wise fertilizer management decisions.

SOIL TEST RESULTS AND NUTRIENT LEVELS

Soil testing is relatively inexpensive and can provide useful information to develop fertilizer management decisions. Soil testing laboratories usually report the levels of plant available nutrient units in either parts per million (ppm) or pounds per acre. When a soil sample represents a depth of 6 or 12 inches, ppm can be converted to pounds per acre by multiplying ppm by either 2 or 4, respectively. For example, a soil test of 10-ppm nitrate-nitrogen is equal to 20 lb/ac in a six-inch depth sample or 40 lb/ac in a twelve-inch depth sample. For nitrate, this number indicates the amount actually present in the soil. For phosphorus or potassium, a soil test result is an index of availability of nutrients. It is critically important to note that a soil test value for most nutrients is not the absolute value. A soil test report with a value of 400 lb K/ac does not mean that the soil only contains 400 lb K/ac. For example, at the Lethbridge Research Station, 66 years of irrigated crop production removed approximately 4000 lb K/ac, while soil test K (0-6”) declined from approximately 800 to 500 lb K/ac (Dubetz and Dudas, 1981).

Soil pH

Soil pH is a measure of soil acidity. The topsoil of most irrigated soils in southern Alberta is alkaline or basic, meaning soils have a relatively high pH. The availability of some soil nutrients is affected by soil pH.

Nitrogen: Soil pH can play an important role in urea vitalization losses. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3). The equilibrium is strongly pH dependent. The difference between NH_3 and NH_4^+ is a H^+ ion. For example, if NH_4^+ is applied to a soil with a pH of 7, the equilibrium condition would be 99% NH_4^+ and 1% NH_3. At pH 8, approximately 10% would exist as NH_3 and 90% as NH_4^+.

This means that urea (46-0-0) is generally subject to higher losses at higher soil pH. But it does not mean that losses at pH 7 will be 1% or less. The equilibrium is dynamic. As soon as a molecule of NH_3 escapes the soil, a molecule of NH_4^+ converts to NH_3 to maintain the equilibrium. However, pH is not the whole story. There are other factors such as soil moisture, temperature, texture and cation exchange capacity that can affect volatilization.

Phosphorus: The form and availability of soil phosphorus (P) is also highly pH dependent. Plants take up soluble P from the soil solution, but this pool of available P in soil solution is extremely small, often less than 1 lb/ac. The limited solubility of P relates to its tendency to form a range of stable P minerals in soil. Under alkaline soil conditions, P fertilizers such as mono-ammonium phosphate (11-55-0) generally form less soluble minerals through reactions with calcium (Ca).

However, contrary to popular belief, the P in these Ca-P minerals will still contribute to crop P requirements. Phosphorus in these forms is referred to as being in labile or residual form. As plants remove P from the soil solution, the less soluble Ca-P minerals in labile form dissolve, and solution P levels are constantly replenished from this label P fraction. Growth chamber and field research has shown that over 90% of the fertilizer P that has formed less soluble Ca-P labile minerals can shift to soluble P forms and will still be available to crops in subsequent years.

Potassium and Sulphur: Availability of these nutrients is not significantly affected by soil pH.

For more information on effect of soil pH on soil nutrients refer to McKenzie (2003)

CATION EXCHANGE CAPACITY

Positively charged elements in soil are cations, which include ammonium, potassium, calcium, magnesium, copper, iron, manganese, and zinc. Clay particles and soil organic matter are negatively charged. Soils tend to hold cations and therefore are normally not easily leached by excess water. The ability of soils to hold cations is measured by the cation exchange capacity (CEC). Units used to determine CEC are milliequivalents per 100 grams of oven-dry soil (meq/100g). Soils with a higher CEC tend to be more fertile and have greater nutrient supplying power to crops. Soils with a CEC less than 5 to10 meq/100 g have a greater potential to lose nutrients by leaching. Soils with a higher

proportion of clay have higher CEC levels. Soils that are very sandy have a lower CEC, lower nutrient supplying power and nutrients are more subject to downward movement under irrigation or excess precipitation.

PERCENT BASE SATURATION

Base saturation refers to the percentage of cation exchange sites in the soil that are occupied by the basic cations, which include calcium, magnesium, potassium and sodium. Normally, base saturation does not have any relation to nutrient availability or to fertilizer recommendations on irrigated land in southern Alberta

Nitrogen (N)

Nitrogen is often the most limiting nutrient in production of irrigated crops except for legumes. Most irrigated crops normally take up most of their nitrogen from the soil in the form of **nitrate nitrogen (NO_3-N).** When soil N level is adequate it promotes vigorous growth and a larger leaf area with a deep green color. Crops obtain N from:

- inorganic nitrate nitrogen (NO_3^--N) and a small proportion from ammonium nitrogen (NH_4^+-N) in the soil solution or attached to soil particles,
- nitrate nitrogen comes from breakdown **(mineralization)** of soil organic matter, manure or residual N from legume crops during the growing season,
- applied nitrogen fertilizer that has converted to NO_3^--N,
- from rainfall associated with lightning.

Almost all N in soil is in organic form and stored in soil organic matter. One per cent of organic matter in soil represents about 1000 lb N/ac. It has been assumed about 1% of N tied up in organic matter is released each year (about 10 lb/ac/year for each 1% of soil organic matter). Soil micro-organisms are responsible for mineralization and release of organic N to NO_3^--N for plant uptake. Several factors influence the activity of these micro-organisms including: the carbon to nitrogen ratio in plant residue and organic matter; and environmental conditions such as soil temperature and soil moisture, and soil organic matter content.

Previously on irrigated fields in southern Alberta, it has been thought that only 10 to 30% (20 to 60 lb N/ac) of the total N required for high yields of irrigated crops is supplied by N released from soil organic matter. Nitrogen fertilizer is required to supply the remaining N. If the previous crop was a legume, an additional 20 to 40 lb/ac of available N is added to soil from breakdown of plant residue. The amount of N fertilizer required depends on the level of soil NO_3^--N. Less fertilizer is needed when the level of plant available soil NO_3^--N is higher.

Crops respond dramatically to N fertilizer on N deficient soils. Under irrigation, high rates of N fertilizer can be economical, but they should only be applied when soil test levels of nitrate-nitrogen are very low.

Fertilizer recommendation tables were developed for a number of irrigated crops and are available on the Alberta Agriculture and Food web site (McKenzie and Kryzanowski, 2003) or can be utilized using the program Alberta Farm Fertilizer Information Recommendation Manager (AFFIRM), available for downing at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop10159.

Recent AF research with irrigated crops has shown that maximum yields tend to be much higher than in the 1980's. Further, control treatments that receive no N fertilizer are much higher yielding in the past. There are several possible explanations for this.

1. Crops have a higher genetic yield potential
2. Improved agronomic crop management including seeding date, seeding rate, crop rotation management, improved pest management contributed to increased crop yields.
3. Improved soil management has resulted in less soil cultivation and possibly improved soil organic matter.
4. Increased crop yields, reduced tillage and increased soil organic matter has resulted in increased mineralization potential of soils to release NO_3^--N for plant uptake.

Figure 1 shows yields of soft white spring wheat research trials at Lethbridge, Barnwell and Bow Island from 2004 to 2006 (McKenzie et al. 2008). The increments of yield increase were quite different among the three sites and varied from year to year. At each site, the yield of the control treatment that received no N fertilizer is relatively high despite low to medium levels of soil test N. The results suggest that considerable soil organic N was mineralized to meet crop requirements. The amount of N taken up by the crop in the control treatment indicates that amount of actual soil N that was available to the crop.

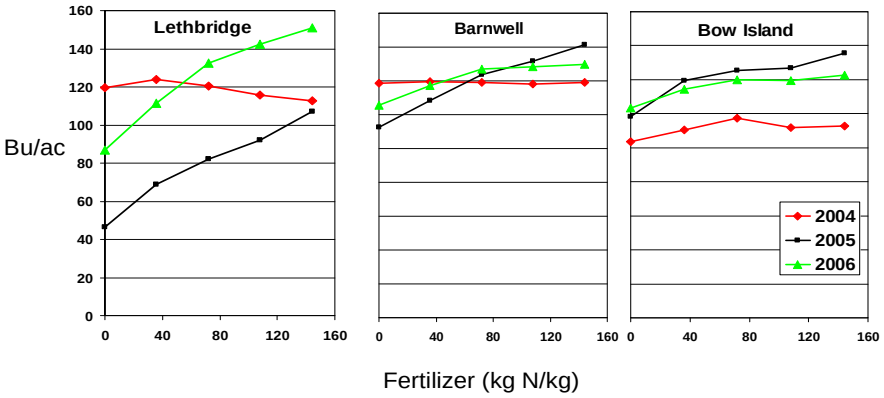

Figure 1. Nitrogen response of soft white spring wheat at nine locations from 2004 to 2005

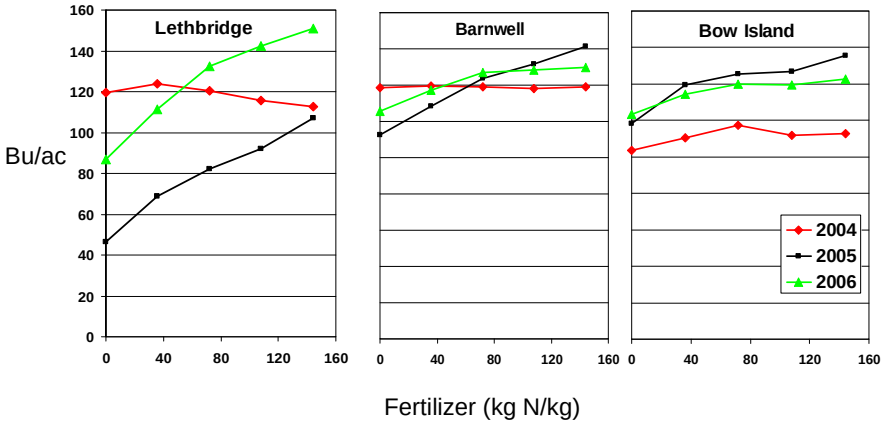

Figure 1. Nitrogen response of soft white spring wheat at nine locations from 2004 to 2005

An examination of 29 irrigated research sites from 1994 to 2006 (Figure 2) shows that the amount of soil test nitrate-N is much less than the total N up take by crops (crop-N) in the unfertilized control treatments. The difference between the crop-N and nitrate-N represents the amount of organic N mineralized and taken up by crops. The average soil nitrate-N level in the 29 fields was 46 lb/ac and the average crop-N taken up by plants was 138 lb/ac. On average the amount of mineralized N taken up by crops

was 92 lb/ac but ranged from 40 to 164 lb/ac. This is a substantial amount of N provided by the soil versus the amount of N that comes from fertilizer to contribute to increased crop yield. From Figure 2, the relationship between nitrate-N and crop-N is very poor (R^2=0.11). It is clear that irrigated soils have a significant ability to mineralize N for crop uptake. However, it is also clear that it is very difficult to predict how much N will be mineralized. This also makes it very difficult to predict how much N fertilizer is needed to achieve optimum crop yield.

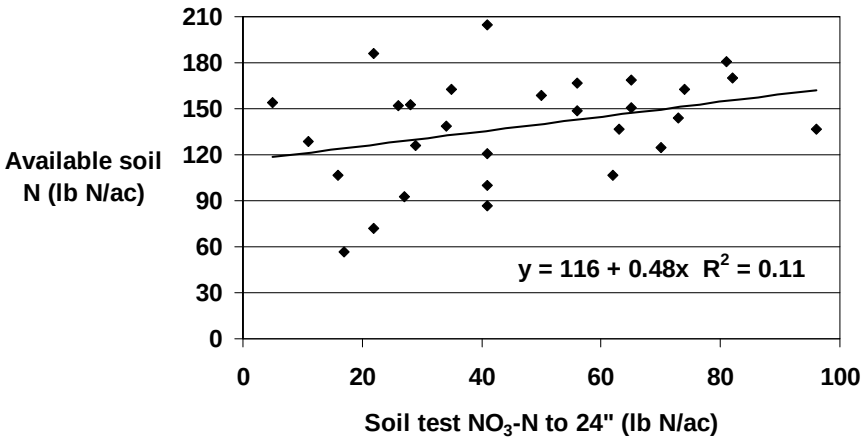

Figure 2. Soil test NO_3-N versus the available soil N taken up by crops.
(Summary of 29 irrigated research sites with barley, mustard and soft wheat.)

The dilemma for producers is how to determine optimum N fertilizer rates. Until new fertilizer response calibration curves are developed, one option is still to soil test to the 24 inch depth for nitrate-N and use the program AFFIRM to estimate economic N yield response based on fertilizer rates. Another option is to apply the amount of N fertilizer to match the rate of N removal of the crop. Basing fertilizer application rate on crop value and N fertilizer price is still the best option. Figure 3 provides an example how cost of N fertilizer will affect the economic rate.

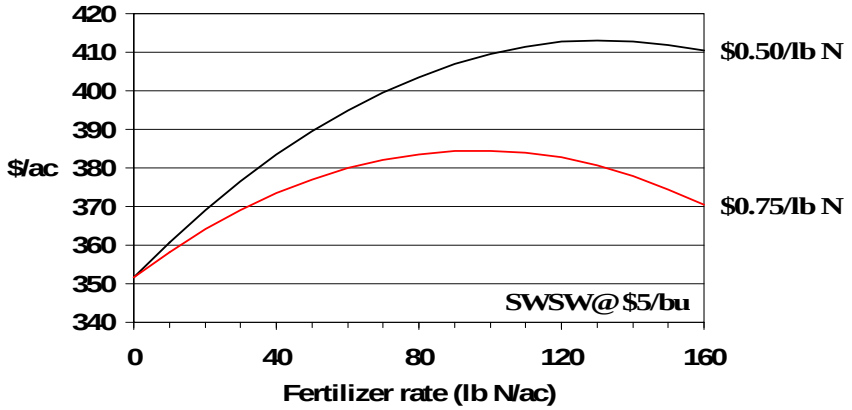

Figure 3. Average net return for soft wheat based on $5.00/ac and an N fertilizer cost of either $0.50 or $0.75/lb of nitrogen fertilizer.

Phosphorus (P)

Soil testing is very useful to estimate the P-supplying power of soils. The modified Kelowna test is most commonly used to estimate the plant-available portion of the total P supply in the soil. In the past several decades, most irrigated soils in southern Alberta have received P fertilizer. The result has been a build-up of labile or residual fertilizer P, most of which can easily shift to plant-available form. Phosphorus fertilizer applied at relatively low rates (15 to 30 lb P_2O_5/ac) generally provides an economic yield benefit for cereal crops such as barley in southern Alberta (McKenzie et al. 2003).

Phosphorus soil tests and fertilizer recommendations in Alberta are not always effective in predicting when a crop will respond to P fertilizer application. Soils that have accumulated fertilizer P over the years may still test marginal in plant-available P, particularly on high pH calcareous soils, yet crops may not respond to added P fertilizer. Some soils that test high in plant-available P still respond to added P. This tends to occur most commonly with annual crops in wet, cool spring conditions. Environmental conditions such as cooler spring soil temperature may result in reduced soil P availability and increased response to P fertilizer.

General phosphorus fertilizer recommendations for irrigated cereal and oilseed crops are in Table 1.

Table 1. Phosphorus fertilizer recommendations at various soil test levels

Soil test level P (lb/ac)	**P_2O_5 recommendation (lb/ac)**		
(0 - 6 inch depth)	**Grains**	**Canola**	**Flax**
> 80	0	0	0
50 - 80	20	20	20
40 - 50	25	30	20
30 - 40	30	35	25
20 - 30	35	40	30
10 - 20	40	50	35
0 - 10	50	60	40

.

For greatest efficiency, phosphate fertilizer should either be seed-placed, side-banded or banded. Germination and emergence can be substantially reduced if more than 20 lb/ac of P_2O_5 is seed-placed with canola or 15 lb/ac of $P_2O_{5\ is}$ seed-placed with flax.

Our research has shown that P uptake efficiency was only 12 to 15% when N (108 lb/ac) and P_2O_5 (54 lb/ac) were dual banded. When N and P were banded separately, P uptake efficiency was 30 to 35%. Apparently, nitrogen can radiate out from the dual-banded fertilizer while the P does not. At high concentrations of N fertilizer, plant roots may be unable to penetrate the band to take-up P fertilizer. When high rates of N fertilizer (>70 lb/ac) are used, banding N and seed-placing P generally gives a better response than dual banding of N and P fertilizer together.

Recent studies have compared residual effects of P fertilizer with repeated annual seed-placed applications. Investigations of the forms of applied P remaining in soil showed that after five years, less than 15% had been converted to unavailable forms. This remaining fertilizer P should be available for subsequent crops for many years.

The fundamental concern farmers have is how much phosphate fertilizer to apply to a crop. When soil test P levels are low and limited amounts of P fertilizer have been applied in previous years, follow the recommendations of soil test report or use Table 2 as a guide. If soil test P levels are medium to high and significant P fertilizer has been

applied in the past 10-20 years, an annual maintenance application of phosphate fertilizer is recommended to meet crop requirements and replenish the soil P that is removed. A maintenance application is the amount of P_2O_5 removed by a crop in a growing season. it might be possible for soil minerals to provide a significant fraction of P_2O_5 removed, and therefore rates sufficient for starter effects (15 to 30 lb P_2O_5/ac) may be sufficient.

Potassium (K)

Soil tests determine the amount of potassium (K) in the soil and fertilizer recommendations are made in terms of potassium oxide (K_2O). Most irrigated crops have a high K requirement, taking up nearly as much K as N. However, seed of cereal and oilseed crops contains only about 20 per cent of the total K taken up by a plant. The remaining K is contained in leaves and stems, which is returned to the soil, unless straw is baled and removed.

Generally, most irrigated soils in southern Alberta have high levels of exchangeable soil K primarily because of abundance of K-bearing soil minerals. Exchangeable soil K is often greater than 500 lb/ac in southern Alberta soils and considerable research in southern Alberta has shown that cereal crop yield is not increased with application of K fertilizer (McKenzie et al. 2004a, 2004b, 2008). In K fertilizer research plots across southern Alberta, application of K has not resulted in a yield response, reduced lodging or reduced disease. Existing recommendations (Table 2) suggest K only needs to be applied to canola when soil test levels are less than 300 lb K/ac and less than 250 lb K/ac for cereal crops. Few southern Alberta fields test less than 300 lb/ac. Potassium may be required on sandy soils with low K levels. The potential for potassium deficiency is greatest on sandy soils that are intensively cropped to potatoes, sugar beets, alfalfa or timothy when these are included in the crop rotation.

Potassium is less mobile in soil than nitrate-nitrogen but more mobile than phosphate. Potassium fertilizers are more efficient when seed-placed or banded. However, even small amounts of seed-placed potassium with canola or flax may reduce germination and emergence. If potassium is required, banding or broadcast- incorporation should be used.

Table 3. Potassium fertilizer recommendations for irrigated grain and oilseed crops in Alberta.

Soil test level K (lb/ac)	**K_2O recommendation (lb/ac)**		
(0 - 6 inch depth)	**Grains**	**Canola**	**Flax**
> 300	0	0	0
250 - 300	0	15	0
200 - 250	15	45	15
150 - 200	45	60	30
100 - 150	60	80	60
50 - 100	100	100	100
0 - 50	120	120	120

Sulphur (S)

Canola and flax have a higher requirement for sulphur than cereal crops. Barley response to S fertilization occurs infrequently in southern Alberta due to the presence of sulphates in irrigation water and subsoils (Bole and Pittman 1984). Fortunately S levels in irrigated soils of southern Alberta are usually more than adequate for crop growth. Much of the S in the topsoil is contained in the organic matter (200 to 600 lb/ac) and is slowly released as sulphate-sulphur (SO_4-S), the form that crops require, through break down of organic matter by soil microorganism activity. Sulphate-sulphur, like nitrate-nitrogen, is mobile in soil, particularly in sandy soils. The topsoil of some irrigated fields may be deficient in plant-available SO_4-S, but the subsoil has enough S in the form of gypsum salts (calcium sulphate) to meet crop requirements. Irrigation water also contains substantial amounts of SO_4-S. Approximately 30 lb/ac of SO_4-S is added to the soil with each 12 inches of applied irrigation water.

A soil test for S can help to determine if S fertilizer is required. Samples should be taken separately from the 0-6, 6-12 and 12-24 inch depths to determine the level of S at various depths. If soil sulphate levels are low in the top 12 inches of soil S fertilizer should be applied to S sensitive crops such as canola. Use **Table 4** as a guide to determine if S fertilizer is required.

It is important to note that research conducted in southern Alberta found that irrigated crops rarely respond to S fertilizer, even at low soil S sites. There are several explanations for this:

-Soils with low levels of SO_4-S in the surface soil often were underlain by subsoils containing adequate levels of sulphate.
-Sulphate-sulphur in irrigation water generally provides ample S to growing crops.
-Rainfall provides about 5 lb/ac of S annually.

Table 4. Sulphur fertilizer recommendations for irrigated crops in Alberta.

Soil test level S (lb/ac)	**S recommendation (lb/ac)**		
(0 - 12 inch depth)	**Grains**	**Canola**	**Flax**
>25	0	0	0
20 - 25	0	10	5
15 - 20	5	15	10
10 - 15	10	20	15
5 - 10	15	25	20
0 - 5	20	30	25

Micronutrients
Micronutrient deficiencies have not been observed in irrigated grain or oilseed crops and yield increases have not been recorded in research plots. Fertilizer trials on irrigated soils in southern Alberta in the 1980's and 1990's did not shown responses to any micronutrients by small grains, canola or flax. Irrigated dry bean is the only crop that has shown response to zinc (McKenzie et al 1999)

Responses to zinc have been obtained with some special crops such as dry beans. Micronutrient fertilizers may be required on land that is severely eroded or that has been machine levelled, thus exposing subsoil. In these cases, maintenance applications of micronutrients may be necessary to prevent future deficiencies. Normally, micronutrient fertilizers are not required by crops in southern Alberta.

Growers who are concerned about micronutrient deficiencies should consult their district agriculturalist or Agdex 531 - 1, Micronutrient Requirement of Crops in Alberta. Producers who wish to try micronutrient fertilizers should soil test first, leave test strips and carefully evaluate the results.

SUMMARY

- Nitrogen fertilizer will often significantly increase crop production. Yield increase charts can be used to assist with determining economic nitrogen rates. The AFFIRM computer program can assist with these calculations.
- Irrigated soils that have been in reduced tillage tend to have a very good N mineralization potential to release plant available nitrate-N and therefore may not respond to higher rates of N fertilizer. Research is presently underway with 11 irrigated crops to re-evaluate crop response to N fertilizers.
- Irrigated crops respond to P fertilizer, but responses are not always well predicted by soil tests. A maintenance application of phosphate fertilizer annually is useful in maintaining good levels of soil P and to ensure adequate P is available for crop optimum crop production
- Potassium and S normally are not limiting factors in yield of irrigated crops in southern Alberta. The naturally high levels of these elements in most southern Alberta soils are generally sufficient for optimum crop production. Soil testing is recommended to determine K and S levels to determine if supplemental fertilizers are required.
- Most irrigated soils are adequately supplied with micronutrients. Most irrigated crops, with the exception of dry beans rarely need micronutrient fertilizers. In the future; more research is needed to improve micronutrient soil testing, calibration and interpretation.

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ESN POTENTIAL FOR IRRIGATED CROP PRODUCTION

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INTRODUCTION

New slow-release, polymer-ESN fertilizer, ESN™ (Environmentally Smart Nitrogen) was registered for use in Canada, in July 2006, for both food and non-food crops. This new polymer slow-release technology was developed by Agrium and is considered a leading edge technology. Over the past 12 years, Agrium Ltd has undertaken development of this unique polymer to coat urea to control the release of nitrogen (N) to improve fertilizer use efficiency and minimize N losses to the environment. Presently, all ESN used in North America is manufactured in Alberta, at the Agrium plant at Carseland.

The efficiency of applied N fertilizer is strongly affected by a number of factors including: environmental conditions, N fertilizer form, and time and placement of N fertilizer. The most common commercial N fertilizer applied to irrigated soils in southern Alberta is urea [$CO(NH_2)_2$]. When broadcast onto the soil surface, urea will convert to ammonia (NH_3) and can, at this stage before conversion to ammonium nitrogen (NH_4^+), potentially be lost to the atmosphere (**volatilization**) at this stage before conversion to ammonium nitrogen (NH_4^+). When urea is placed in warm, moist and well-aerated soil, ammonium is rapidly oxidized to nitrate nitrogen (NO_3^-) by **nitrification**, a biological process performed by specialized soil bacteria. Loss of nitrate is caused when soils are warm and wet causing an anaerobic process (**denitrification**), where soil microbes strip oxygen from nitrate to convert it to gaseous nitrogen forms. Wet soil conditions will also result in downward movement of nitrate below the plant root zone and into ground water (**leaching**). Plant available soil N can be **immobilized** by soil micro-organisms. This N is not lost from the soil but is tied up temporarily and is released slowly for crop use through **mineralization**, a process were soil N in organic form is broken down and released my soil microorganisms. It is important to remember that soil microbes compete with growing crops for applied nitrogen fertilizer, which may result in reduced crop growth.

Volatilization potential will increase when:

- urea fertilizer is broadcast onto the soil surface but not incorporated or poorly incorporated into soil
- soil temperature is > 5 C and air temperature is > 10 C

- soil surface is moist or dew occurs in mornings
- no rain or irrigation occurs to move the fertilizer into the soil

Denitrification potential will increase when:

- nitrate nitrogen is present in soil
- soil temperature is > 5 C
- soil moisture conditions are very wet and oxygen levels are low in soil

Leaching potential will increase when:

- nitrate nitrogen is present in soil in significant amounts
- soil moisture level is above field capacity
- excess precipitation or over irrigation occurs
- soils are coarse textured

Immobilization will increase when:

-when the amount of crop residue which contains carbon (C) increases, the amount of soil N immobilized by microbes will increase

-when the ratio of C : N increases in crop residue immobilization will increase.

-when the ratio is 20 or higher, immobilization will increase.

To minimize potential N losses from soil, Agrium has developed a new slow release fertilizer product, ESN. The ESN product is commercial urea fertilizer with a very thin polymer coating. The porous polymer coating permits water to slowly permeate through the coating into the fertilizer granule to dissolve the urea, then dissolved urea gradually diffuses through the polymer coating into the surrounding soil. Typically, commercial urea when placed in warm moist soil will convert to nitrate-N over a period of several weeks. When the fertilizer form has converted to nitrate, it is potentially subject to denitrification and leaching losses.

The polymer coating causes the urea to slowly release the N. Soil moisture and temperature are the two environmental factors that have the greatest effect on the rate of urea release from the encapsulated granule. By coating urea fertilizer granules with this polymer, the urea is protected from significant environment losses and the conversion to nitrate occurs slowly over a period of about six weeks depending on soil temperature and moisture.

ESN polymer ESN offers irrigation farmers in southern Alberta the following opportunities:

1. To reduce potential N fertilizer losses (volatilization, denitrification and leaching), under specific environmental conditions, which in-turn could result in increased nitrogen fertilizer use efficiency, result in higher crop yields and improved crop quality.
2. ESN could lead to reduced N fertilizer requirements if N fertilizer uptake was more efficient; higher yield potential of 5 to 10 %, and higher protein levels for crops such as spring wheat or durum with premium payment for higher protein.
3. ESN can potentially be safely seed placed at 3 to 4 times the safe rate of commercial urea.

The purpose of this paper is to present information on the performance of ESN with different crops and different environmental conditions, to aid producers in their decisions if this product would be beneficial in their irrigated cropping systems.

Seed-Placed ESN Potential

Recent work with two proto types of polymer ESN seed-placed with winter wheat, showed that up to 120 kg N/ha of ESN could be safely seed-placed versus only 30 kg N/ha of urea (McKenzie et al. 2007). Stand densities were substantially reduced by seed row application of urea at rates greater than 30 kg N/ha, but were unaffected by seed-placed application of ESN, even at the highest rate of N application. When N fertilizer was side-banded, stand densities were unaffected by fertilizer type or N rate. Yield gains due to N application were reduced by application of high rates of seed-placed urea, but similar for other treatments. Grain protein concentration and N uptake were also similar for ESN and seed-placed urea.

Much higher rates of ESN versus urea could likely be seeded-placed with spring wheat, barley and canola. A field research project in southern Alberta is presently examining this under various environmental conditions. If substantially higher ESN rates can be seed-placed with reduced N losses, this could have a huge benefit to prairie farmers. Additional field operations, specifically to apply N fertilizer, could be eliminated and all N fertilizer could be safely seed-placed. For direct seeding systems, single shoot openers could be used instead of more costly double shoot openers, which are presently needed to side band higher rates of N fertilizer. Using single shoot openers versus double shoot openers would reduce soil disturbance, conserve soil moisture, reduce horsepower requirements and lower fuel consumption.

Figures 1 and 2 show the effects of four N treatments:

1. Urea side banded (Urea-SB)
2. Urea seed-placed (Urea-SP)
3. ESN seed-place (ESN-SP)
4. Blend of Urea's at 25:75 seed-placed (Bl-SP) at rates of 0, 30, 60, 90 and 120 kg N/ha with canola and barley at Bow Island in 2007.

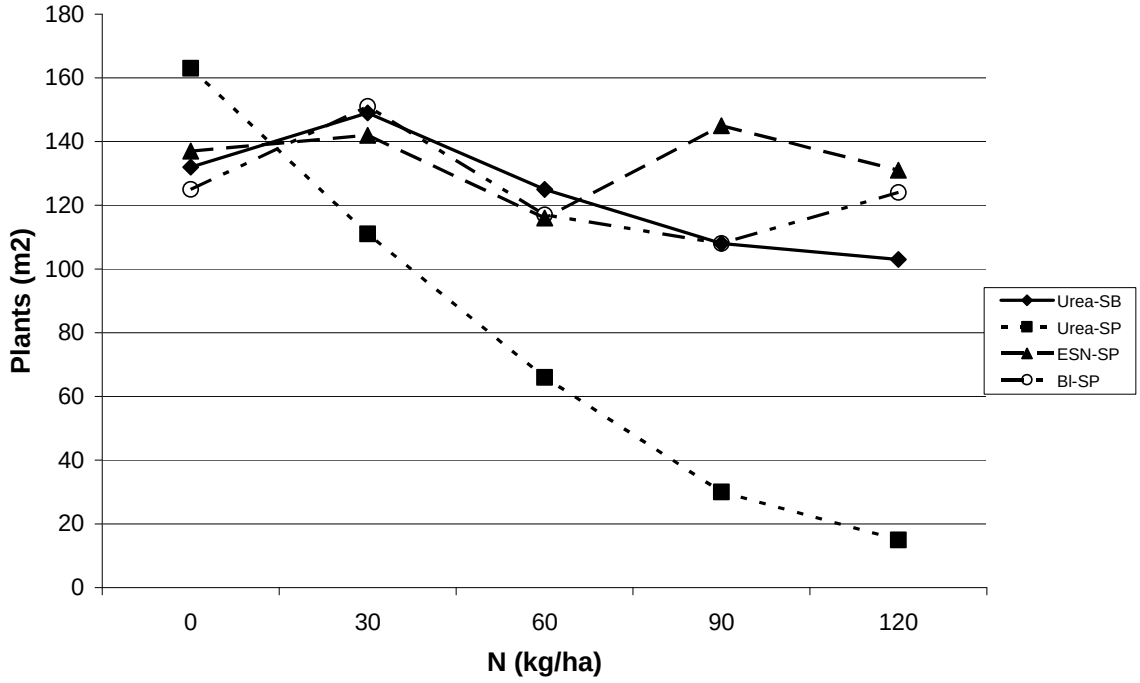

Figure 1. Effect of N treatments including Urea side banded (Urea-SB), Urea seed-placed (Urea-SP), ESN seed-place (ESN-SP) and Blend of Urea:ESN at 25:75 seed-placed (Bl-SP) at rates of 0, 30, 60, 90 and 120 kg N/ha with canola at Bow Island in 2007.

Trials were conducted at five dryland locations across Alberta in 2007 with wheat, barley and canola. Generally, seed-placed ESN at rates higher that 60 kg/ha had higher plant counts than seed-placed urea. The difference in plant counts was minimal when soil moisture conditions were very good at and after seeding. Generally, the difference in crop yield on the dryland sites was minimal due to very dry summer conditions. Work under irrigated conditions is required to determine the safe seed-placed rates and the benefits of seed-placed ESN in terms of plant establishment, yield and N use efficiency to determine the cost:benefit of using ESN versus urea in various placement scenarios.

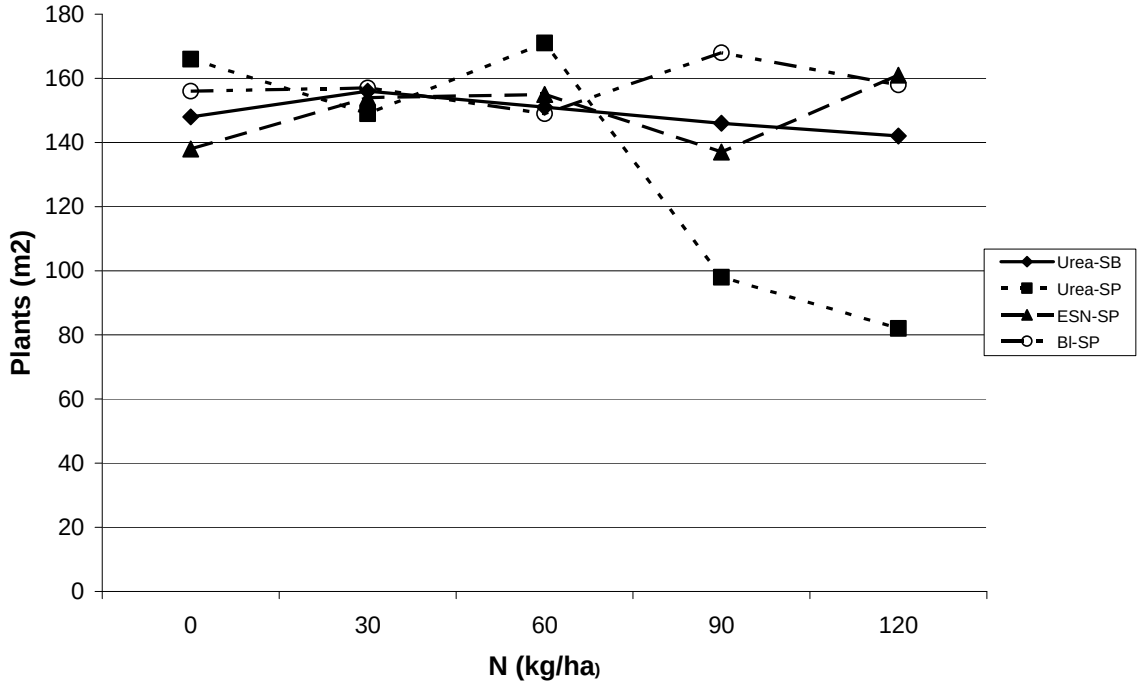

Figure 2. Effect of N treatments including Urea side banded (Urea-SB), Urea seed-placed (Urea-SP), ESN seed-place (ESN-SP) and Blend of Urea:ESN at 25:75 seed-placed (Bl-SP) at rates of 0, 30, 60, 90 and 120 kg N/ha with barley at Bow Island in 2007

Preliminary results with cereal crops suggest that moderately high rates of ESN can be safely seed-place using a single shoot system, but research info is preliminary and must be used with caution. For wheat and barley, the safe ESN rate will likely be between 50 to 80 lb N/acre using a narrow opener with a 10% seed-bed utilization (SBU). For canola and other sensitive crops more research needs to be conducted before providing recommendations.

A major caution is that ESN fertilizer must be handled carefully. ESN is simply urea coated with a polymer to slow the release and eventual conversion of urea to ammonia. Rough handling may crack the polymer coating, resulting in failure of the technology and increase the risk of seedling damage. Some samples obtained from air seeders have had significant damage of 40 to 50% as a result of bashing within the air system. If a farmer were to seed-place the safe rate of urea, then apply an additional 70 lb N/ac using ESN that had 40% fractured granules, there would be a high potential for crop injury. This is a very major concern! Further work is needed to determine the effects of damage to granules in various handling systems.

Use of Broadcast ESN onto Winter Cereals
In a study with winter wheat, three N fertilizers (ESN, urea and ammonium nitrate) were broadcast at 30 kg N ha^{-1} in early spring on plots that had received 0, 30 or 60 kg N/ha at the time of seeding. Inadequate release of spring broadcast ESN was indicated by reduced grain protein concentrations relative to conventional N fertilizers. Under the conditions experienced, ESN was less effective than conventional N fertilizers when broadcast in early spring.

Fertilizing winter crops in early spring with urea can be very effective, when soil and air temperatures are cool. ESN does not perform very well on winter cereals when broadcast in early spring as it has too slow a release rate. It does not release and move into the soil quickly enough to meet crop requirements. The granules remain on the soil surface are release only small amounts of N.

ESN Use with Irrigated Timothy
Two field experiments were conducted with Irrigated Timothy at two locations, at Bow Island and Lethbridge (Hohm et al. 2005). The first production year at Lethbridge was in 2004 and at Bow Island was 2005. Both sites were terminated in fall, 2007.

The first experiment evaluated the effects of spring broadcast ammonium nitrate, urea and ESN at rates of 0, 50, 100, 150 and 200 kg N/ha. At both Lethbridge and Bow Island (first cut) in each year, the spring broadcast ESN treatments consistently yielded lower than the urea and ammonium nitrate treatments. Varying nitrogen rates resulted in a significant yield response for both first and second cutting at both locations. In 2005, yields increased significantly to the 150 kg/ha treatment at Bow Island on the first and second cut. At Lethbridge, nitrogen rates resulted in significant yield response on the first cut to 150 kg ha^{-1}, however, for the second cut at Lethbridge, yield increased to the 200 kg ha^{-1} treatment.

The second experiment evaluated four treatments: a check (0 kg N/ha); early fall ESN broadcast application at 100 kg N/ha; ammonium nitrate spring broadcast at 100 kg N/ha; and 75 kg N/ha spring broadcast ammonium nitrate + a simulated fertigation application of 25 kg N/ha ammonium nitrate. For nitrogen fertilizer type and timing at both locations, yield results of the fall applied ESN treatments were the lowest (significant) for first and second cut. Data suggests that release of ESN was too slow and there was possibly volatilization from stranded granules on the soil surface or the thatch layer of residue. A contributing factor to the delayed release is possibly due to the ESN getting hung up in the heavy thatch layer. ESN granules were found within the thatch layer weeks and even months after broadcast application.

ESN Potential with Long Season Irrigated Crops.
ESN is considered to have potential to increase N use and N use efficiency with longer season irrigated crops such as potato, sugar beet and corn, particularly when grown on

sandy soils that have higher leaching potential. Potential benefit would also be increased when excess precipitation occurs in the first 60 days after planting because ESN is slowly released into soil.

A preliminary trial with urea and ESN combinations was conducted at Brooks, in 2006. Results from this preliminary trial indicated that a 50:50 split of urea and ESN at planting resulted in the greatest marketable yield. These results and a recent decision by CFIA to accept the use of ESN in potato production has piqued the interest of potato growers in Alberta.

To examine ESN with potatoes, a new study was initiated by AF in southern Alberta in 2007 at sites located near Vauxhall and Taber. The purpose of this research is to determine whether ESN can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality. The use of polymer coated urea in potato production could potentially increase nitrogen use efficiency and reduce the total amount of nitrogen required to grow a high quality processing potato crop. The objectives of this new study are:

1. To determine the effect of combinations of urea and ESN on yield, specific gravity and quality of Russet Burbank potatoes; and
2. To determine whether ESN can replace the need for in-season N applications (top-dressing, side-dressing or fertigation), and
3. To determine whether ESN reduces the risk of nitrate leaching in irrigated potato production; and
4. To determine whether ESN can be used as a tool for better nitrogen management in Alberta potato production.

Various combinations of urea and ESN (polymer-coated urea) were used pre-plant and compared with urea at planting followed by top-dressing at emergence to determine if ESN could be used to replace a nitrogen application in-season. The fertilizer treatments included:

1. No additional nitrogen (approximately 70 kg/ha based on soil test) – check
2. Urea applied pre-plant to bring available N to 225 kg/ha (155 kg/ha)
3. Urea applied pre-plant to bring available N to 170 kg/ha (100 kg/ha)
4. Urea applied pre-plant to bring available N to 115 kg/ha (45 kg/ha)
5. ESN applied pre-plant to bring available N to 170 kg/ha (100 kg/ha)
6. ESN applied pre-plant to bring available N to 115 kg/ha (45 kg/ha)
7. Urea applied pre-plant to bring available N to 170 kg/ha (100 kg/ha) plus 55 kg/ha ESN applied and cultivated in at emergence (Urea/ESN split)
8. Urea applied pre-plant to bring available N to 115 kg/ha (45 kg/ha) plus 55 kg/ha ESN applied and cultivated in at emergence (Urea/ESN split)
9. Urea applied pre-plant to bring available N to 115 kg/ha (45 kg/ha) plus 55 kg/ha ESN applied and cultivated in 2 weeks after emergence (Urea/ESN late split)
10. Urea applied pre-plant to bring available N to 170 kg/ha (100 kg/ha) plus 55 kg/ha urea applied and cultivated in at emergence (Urea split – STD)

In 2007, at the Brooks site, there was no significant difference in total or marketable yields amoung treatments, but the greatest total yields in Brooks were observed when 100 kg/ha ESN was applied pre-plant and when an application of urea was used (STD).

Several treatments (Trt #2, 3, 5, and 10) resulted in greater yields of 6 to 10 oz tubers than the check. Yield of most other size categories were not significantly different.

Specific gravity of tubers from the various nitrogen treatments was not significantly different from the check, although some treatments showed significant differences from one another. In Brooks, urea or ESN at 50 kg/ha resulted in the greatest SG, while higher levels of nitrogen pre-plant reduced SG relative to the check.

At Vauxhall (Table 1), the greatest total yield was observed when urea was applied pre-plant and ESN was applied after emergence (Trt #9). The split urea application resulted in the greatest yield of undersized tubers. The best marketable yields were observed when urea was applied pre-plant and ESN was applied after emergence (Trt #9) and when ESN was applied at emergence at 100 kg/ha (Trt #7). Specific gravity of tubers from the various nitrogen treatments was not significantly different from the check, although some treatments showed significant differences from one another. At Vauxhall in general, low pre-plant N rates tended to have higher SG, while high N at planting resulted in lower SG.

Table 1. Potato response to various N fertilizer treatments in 2007.

Trt #	Treatment	Total N	% of STD	Mkt Yld (ton/ac)	6-10 oz. (ton/ac)	SG
1	check	70	30%	16.7 b	4.7 ab	1.095 ab
2	100% urea pre-plant	225	100%	17.6 b	5.2 ab	1.094 ab
3	75% urea pre-plant	170	75%	18.1 ab	5.9 ab	1.094 ab
4	50% urea pre-plant	115	50%	19.7 ab	5.8 ab	1.098 ab
5	75% ESN pre-plant	170	75%	16.9 b	4.6 b	1.096 ab
6	50% ESN pre-plant	115	50%	16.8 b	4.9 ab	1.100 a
7	75% ESN at emergence	170	75%	20.2 ab	4.5 ab	1.098 ab
8	75% split (urea pre-plant, ESN at emergence)	170	75%	18.8 ab	10.9 a	1.092 b
9	75% split (urea pre-plant, ESN late)	170	75%	22.3 a	7.4 ab	1.096 ab
10	STD (urea pre-plant, urea at emergence)	225	100%	16.4 b	5.7 ab	1.094 ab

This potato study was the first year of a three-year trial. A total of 6 site years of data will be generated and should provide sufficient information to develop recommendations for incorporating ESN as part of a nitrogen management strategy for potato producers.

SUMMARY

Initial work with seed-placed and banded ESN with winter wheat has been very positive. However, spring broadcast application of ESN on both winter wheat and irrigated timothy has not been as effective as broadcast ammonium nitrate or urea.

ESN does have good potential for seed-placement with spring-seeded crops as demonstrated by Brant et al. (2005) and in Alberta Agriculture and Food trials. Safe rates will have to be determined for crops such as wheat, barley and canola in different soil and agro-ecological areas.

The potential for increased N use, N fertilizer use efficiency and increased crop yield with cereal, oilseed and special crops under irrigation will require considerable research to determine the crops and environmental conditions when ESN is or is not potentially effective.

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IRRIGATION WATER SUPPLY OUTLOOK – 2008

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The determination of expected irrigation water supplies in advance of the irrigation season is based on science, some simple mathematics and with a little crystal balling thrown in. The volume of water available for irrigation is based on a combination of a number of factors, all of which are tied to the weather. The three key factors include: water in storage; snow packed in the Rocky Mountains and in-season precipitation.

Reservoir Storage

The only factor which is known with a great amount of certainty is the volume of water, which is already in storage. Not surprising the volume of water in storage does not fluctuate very much during the fall and winter as the amount of water needed to maintain a healthy aquatic system usually requires that most of the flow comes in one end and out the other. Storage reservoirs are the heart of the irrigation water distribution system, and when filled to capacity allows for a considerable amount of flexibility when managing short water supplies. Over all, without storage reservoirs the irrigation system as we know it would be short of water by the first of July in nine out of ten years.

In the irrigated area of Alberta there are 58 constructed reservoirs, which hold from 320 acre-feet to almost 400,000 acre-feet and have a total storage capacity of approximately 2.44 million acre-feet. Not all of this water is available for irrigated agriculture as most were designed in support of inter-provincial apportionment, recreation and aquatic eco-system preservation.

Because of the measuring and monitoring on each of these reservoirs we have a very good understanding of the volume of water which would be available for irrigation purposes the following year.

Snow Pack

The provinces largest reservoir is the Rocky Mountains and the snow packed into them throughout the winter. Knowing how much water is contained in the snow is where science takes over and the crystal balling comes into play. If you look out the window you see a snow covered mountain and could quickly come to the conclusion that there is a considerable amount of snow/water available.

The science of measuring and calculating the amount of snow and the snow/water equivalent is determined by knowing the weight of the snow. The provincial government has a number of automated snow monitoring site strategically located in the headwaters of our major river basins. These snow monitoring sites could be described as over sized water beds which measures the weight of the snow. As the snow piles up on the

bed it pusses down which in turn lifts up a level meter. If the snow is deep but light and fluffy it holds less water than a heavy well packed snow fall.
Throughout the winter these snow pillows are monitored and monthly estimations made on the volume of water which could be expected from the mountain snow. Knowing how much water is held in the snow is only one part of the equation – knowing how quickly it melts is where the crystal balling comes in. If it warms up too quickly and we get a warm rain on the snow it could runoff quickly and we may not capture it as the on-stream reservoirs fill too quickly. If it warms up too slowly much of the snow pack will evaporate and not runoff to the rivers to be stored.
The following is a sample water supply forecast which is available throughout the season.

Water Supply Outlook for Alberta

Table - Water Supply Forecast as of May 1, 2007 - Oldman River Basin (Natural Flows)

	Volume Forecast for March 1 to September 30, 2007					
Locations	**Volume in dam^3**	**Volume as a % of Average**	**Probable Range as a % of Average**	**Reasonable Minimum as % of Average**	**Forecast Ranking (lowest to highest)**	**Recorded March-September 2006 Volume as a % of Average**
St. Mary River	701,000*	94	80-105	74	39/91	95
Belly River	229,000	94	84-112	77	34/91	94
Waterton River	581,000	96	81-111	74	41/91	93
Oldman River near Brocket	1,043,000	96	80-114	68	44/91	83
Oldman River at Lethbridge	2,738,000	92	73-107	65	44/91	89

Precipitation
Environment Canada provides long and short term forecasts for expected precipitation but we all know how much we think the weather men knows. This is where the crystal ball is needed most. To estimate the amount of precipitation we expect in the growing

season we use long-term averages and then run water supply estimates for the highest 25% of years, the average years, and the lowest 25% of precipitation years. By doing this we can come up with conservative estimates for the dry years, as well as some very liberal estimates based on the potential of it being a wet year. The year 2001 was one of those years where the total growing season precipitation was much below even the lowest 25% of years combined with low snow pack and reservoirs which were below normal operating levels and the irrigation users receiving water from the southern tributaries found themselves in a deficit situation. The following table identifies how water supplies are determined and if these numbers were to be divided by the number of acres being irrigated in the basin this would result in the water supply availability for the up-coming irrigation season. If added to predicted precipitation a total volume of water available for growing a crop would be understood.

Parameter	Value at Reasonable Minimum	Value at 75% Probability	Value at 50% Probability	Value at 25% Probability
Reservoir Storage (ac-ft):				
> AENV Headworks	425,900	425,900	425,900	425,900
> District Internal	261,377	261,377	261,377	261,377
> SUB-TOTAL (ac-ft)	**687,277**	**687,277**	**687,277**	**687,277**
Forecast Watershed Yield (ac-ft):				
> St. Mary River Sub-Basin *	336,884	369,486	456,424	521,628
> Belly River Sub-Basin	135,189	149,609	169,436	203,684
> Waterton River Sub-Basin	302,003	337,533	408,593	484,094
> SUB-TOTAL (ac-ft)	**774,076**	**856,628**	**1,034,453**	**1,209,405**
Other Allocation Commitments (ac-ft):				
> Minimum In-Stream Flows (ac-ft)	76,860	76,860	76,860	76,860
> U.S. Share of St. Mary River (ac-ft) **	101,065	110,846	136,927	156,488
> Other Licensee Apportionments (ac-ft)	31,800	39,750	45,050	53,000
> Storage and Conveyance Losses (ac-ft)	16,931	15,729	15,512	16,153
> SUB-TOTAL (ac-ft)	**226,656**	**243,185**	**274,350**	**302,502**
Net Available To Irrigation Users (ac-ft):	**1,234,697**	**1,300,720**	**1,447,381**	**1,594,180**

ALBERTA 2007 INSECTS

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INTRODUCTION

Insects received their fair share of attention once again in 2007. There was a collection of the old, the new and also some of our occasional visitors to the scene. Cabbage seedpod and pea leaf weevil were the pest species responsible for greatest economic damage to Alberta cropland in 2007. Cereal leaf beetle was confirmed in several more counties.

OILSEED INSECTS

Cabbage seedpod weevils were a large concern in southern Alberta this year. Economic threshold levels occurred in many fields and near threshold densities in many others. Control operations were widespread in the Lethbridge region, especially in the earliest seeding/flowering fields. Early bloom seems to draw weevil adults into the fields. No strong forecast model exists for CSPW but based on last years population we are expecting more problems in 2008.

Bertha armyworm moth catches suggested a potential problem was in the making. In the end fewer fields were treated for Bertha armyworm than expected. Once again excellent cooperation of industry partners made a successful monitoring program possible. The forecast for 2008 is very uncertain. It will be important once again to carry out a broad based survey for adult moths in order to see what the expected population will be.

Diamondback moth was monitored in Alberta again in 2007 as part of a project through Maya Evenden at University of Alberta. Moth numbers were on the increase as harvest approached but no damaging populations were observed. DBM is a year by year situation because populations depend on migration from the southern United States. This insect has to be watched each year to catch the build up from the migrating populations.

Lygus bugs are usually not a concern in irrigated canola. Lygus bugs are usually a problem when we have extended hot and dry conditions through the summer. A fall outbreak of lygus usually follows a warm dry spring and an extended warm dry stretch of weather in late summer. Occasionally extreme populations of lygus in the spring

have followed a warm dry summer in the Peace country but we have not seen that situation in southern Alberta.

A common insect in canola fields across Alberta this year was the salt marsh caterpillar. Although unlikely in economic numbers, this fuzzy fiend was noted throughout most of Alberta. This insect is unlikely to be common two years in a row.

CEREAL INSECTS

Cereal leaf beetle population levels remain very low although it has been found in a wider area in southern Alberta. The area around Lethbridge appears to have the largest populations so far. Natural enemies are not yet a factor in the population. It is possible that damaging populations could occur in the immediate Lethbridge area in 2008.

Slugs in wheat and canola were seen in central Alberta. Some fields in the Westlock/Barrhead areas had upwards of 50% of the field denuded by slugs early in the season. This is likely the introduced species of garden slug. The damage is similar to that caused by cereal leaf beetle, except the slugs leave a slime trail. The damage tended to be in low-lying areas of the field. This is something we may want to be aware of in southern Alberta irrigated fields as well.

PULSE CROP INSECTS

Pea leaf weevil expanded its range and level of damage again over last year. A minor use registration for Matador and an emergency use registration for Crusier seed treatment helped producers with control options. There remains concern over thresholds and spray application timing. Many acres were sprayed but producers still noted damage to nodules and root systems. The 2007 survey showed that the distribution has expanded north of Calgary in the west and well north of Medicine Hat in the east. This weevil is also causing concern in fresh peas in commercial, market garden and home garden situations.

GRASS CROP, PASTURES AND GENERAL INSECTS

Numbers of pest species of grasshoppers remain very low in southern Alberta and are unlikely to be a significant concern in 2008 for irrigated crops.

Alfalfa weevil damage was common again in southern Alberta fields.

Mite in timothy. This is a mite that has shown up a few times in the past couple years. At first it was wrongly identified as brown curl wheat mite (*Petrobia latens*). This year an

identification done by Fred Beaulieu, Mite Specialist Agriculture and Agri-Food Canada, identifies the pest as likely *Bryobia lagodechiana*. This has been a problem in older stands of irrigated timothy, at first glance the crop appears to be under severe moisture stress.

STORED GRAIN INSECTS

The 2006/2007 grain storage year was heavily impacted by stored grain insects including many infestations of the rusty grain beetle. Insects identified also included psocids, mites, foreign grain beetles, spider beetles and red flour beetles. The 2007/2008 grain storage period may also see problems with the potential of carry over populations from last year.

CONCLUSION

In crop production one constant is that there will be insects. In Alberta we have been relatively lucky because most of our insects have been cyclical. We use far less insecticides than most crop producing areas of the world. Some of the new introductions may change the cyclical nature of insect outbreaks in Alberta.

2007 DISEASE SYNOPSIS AND FORECAST FOR 2008

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Paper Available as Handout

IRRIGATION WATER MANAGEMENT FOR CROP PRODUCTION: THEORY

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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, such as pre-mature ripening or light kernel weight, can be a result of water stress during reproductive stages.

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 energy cost.

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

SOIL PHYSICAL PROPERTIES

Soil Texture

Soil texture is defined as the relative proportions of the soil mineral components (sand, silt and clay) (Gregorich et al. 2001). Textures are grouped into categories (e.g. clay loam) based on these relative amounts. The texture triangle is often used to used to determine the soil texture category from relative proportions of sand, silt and clay.

It is important to be familiar with soil texture, as it determines a soil's water holding capacity (wilting point, field capacity, available water), infiltration rate, suitability to irrigation and irrigation techniques, susceptibility to wind and water erosion, potential for problems with crusting or water logging and tillability/drawbar pull.

Water Holding Properties

Once soil texture is determined, other soil physical properties can be estimated from it. 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 components, which include mineral and organic materials. This porous volume may be occupied by air or water and both are necessary for crops to thrive. When the entire porous volume is filled with water, the soil is said to be saturated. However, in a field situation, soil is seldom able to reach full saturation. Air pockets will be trapped in small pores and water will drain quickly from very large pores, so the term field saturation or maximum retentive capacity is used to describe a soil that is saturated under field conditions (Brady and Weil 1999).

The field capacity of a soil is the soil water content after a field 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 water that drains during this period is referred to as gravitational water and is generally unavailable to plants because it remains in the soil for too short a period and because plant respiration is impeded at these high levels of water content due to lack of soil air. In the laboratory, field capacity is determined by measuring the soil water content at a suction of -30 kPa (0.3 bars). Under field conditions, field capacity can be estimated by measuring the soil water content after a field-saturated soil has been left to drain for about 2 to 3 days, and less for sandy soils (Hillel 1998).

The wilting point, sometimes called permanent wilting point, is defined as the soil water content at which a plant can no longer draw water into its roots from the soil. For this reason, any water remaining in the soil is unavailable to plants. The permanent wilting point can be determined, in the laboratory, by measuring the soil water content at a suction of -1500 kPa (15 bars) (Soil Science Society of America 1997). 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).

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/hr)**
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)

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 millimeters of water per meter depth of soil. To convert the mm/m values to inches per foot, divide by 83.3. When irrigation recommendations are made, they are often given in terms of allowable depletion. This is the percent of available water that is safely allowed to be depleted between irrigations.

In order to clarify these definitions, Figure 1 shows a graphic representation, called the “bucket model” (Hillel 1998). This model is a simplified way of demonstrating the relative amounts of unavailable, available and gravitational water in a soil. Here, all the pore space in a soil is imagined to be separated from the solid particles (e.g. sand, silt, clay and organic material) and collected together in a bucket. This example shows the bucket model for a clay loam soil. It has a wilting point of 16%, a field capacity of 36% and 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). If, for example, an irrigation recommendation suggested that the safe allowable depletion for a given crop is 40%, this means that, for optimal crop growth, the available water can be depleted by 40%, or to 60% of total available water. For a clay loam soil (Figure 1), this would be at 28% of the volumetric soil water content. It is clear that these definitions can sometimes be confusing. Crop irrigation management recommendations are traditionally given as the percent of available water rather than a percent of total volume (Figure 1), however many of the instruments that are used to measure soil moisture in a field, provide estimates as a percent of total volume, so it is important to always clarify what is required.

It is evident from Table 1 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/hr, whereas a saturated clay soil will have an average infiltration rate of only 0.6 mm/hr, 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.

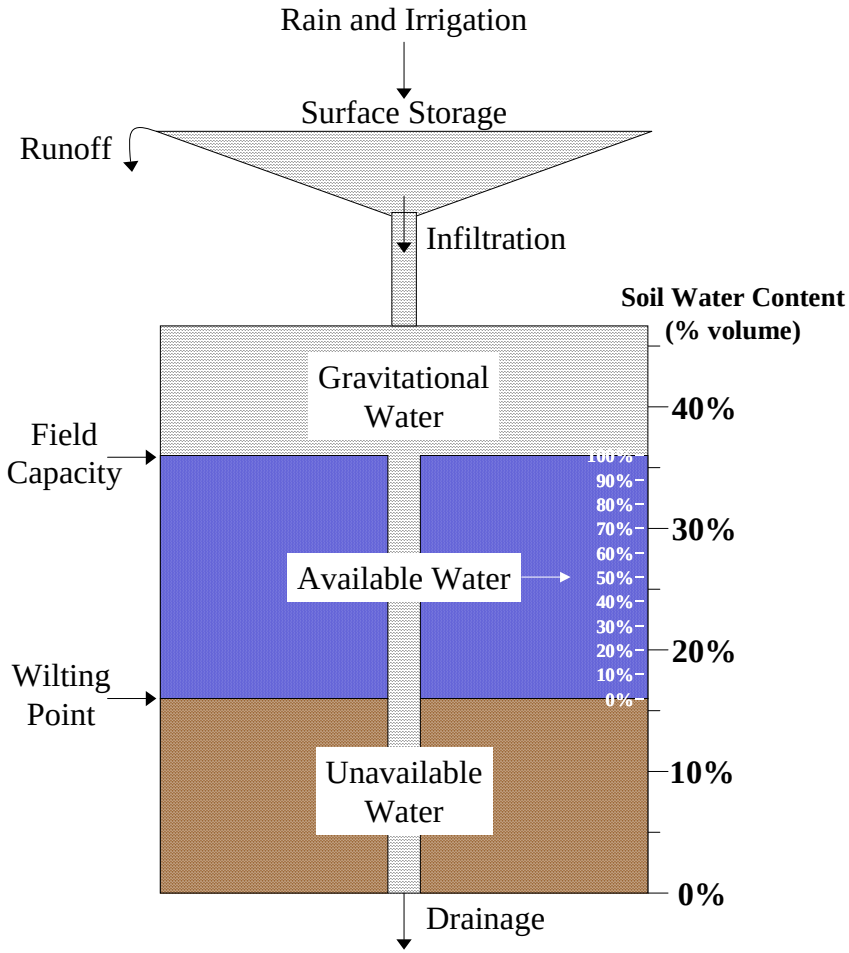

Figure 1. The “bucket model” representation of soil moisture availability of a clay loam soil (Adapted from Hillel, 1998).

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 or by oven-drying of cored samples, with numerous soil moisture sensors, by direct measurement of crop use or with crop water use models, such as the Albert Irrigation Management Model (AIMM) (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 21˚C (Alberta Agriculture, Food and Rural Development, 2002a). This practice is not necessary for alfalfa grown for forage.

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 texture, available water holding capacity and infiltration rate. Soil physical properties can vary among and within fields, so it is important to be familiar with the properties of all fields being managed. It is also essential to understand the soil physical characteristics for a range of depths within a field. Crop type, variety and growth stage will determine in-season water demand, which can be monitored by determining soil moisture content, using core samples, various soil moisture probes, water use models or a combination of these.

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 Forage Seed	 620 510	40	1.2			 561-14 100/32-1
Barley Forage Malt	 390 430	50		70% from 0.5m	tillering and throughout flowering	561-15
Canola	480	50	1.2	70% from 0.5m	late vegetation/spiking and throughout flowering	561-5
Corn Fresh Silage	 430 510	50	1.0		25-30cm tassel and ear initiation	100/32-1 U of Nebraska
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 Dry Fresh	 400 375	60	0.8	70% from 0.4m	throughout flowering and into pod development and filling	561-11
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 Soft Hard	 480 460	50	1.0	70% from 0.5m	tillering and flowering	 561-13 561-4

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PRACTICAL METHODS TO CARRY-OUT IRRIGATION SCHEDULING

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Background Points:

1. Return on investment from Irrigation Scheduling is usually very good, if you are simply too busy to do the work, it is likely worthwhile to hire someone else to do it.

2. Review the fundamentals: Refer to Shelly Woods presentation.

3. Remember that every soil reservoir is different, and in Southern Alberta there may be several different reservoir capacities in the same field.

4. Irrigation Scheduling is somewhat like financial budgeting; an inexact science at the best, but this doesn't mean you still can't benefit from the process. This is one place where you can do a half baked job and still be better off than if you just use the Coffee Shop Method.

A Practical Plan:
(One of many ways to tackle this problem)

1. Learn about what you have to work with. You really do need to understand reservoir capacity (a.k.a. "Bucket Size")

2. In the spring; set up an Available Moisture chart for each crop on each field. Get used to working in mm; in the long haul it is much easier.

3. Draw in the "Red Line" or Allowable Depletion Level. You can't fall below it.

4. Monitor your soils on a regular basis, Monday morning works well, or how about Sunday evening. The accuracy of the measurements isn't the important part, doing it is. Plot your current level on the chart, this gives a visual representation of how much is left.

5. Estimate the crop use using standard data and predict what your level will be at the end of the week. This is just an educated guess, but it can still help you avoid wrecks.

6. Calculate how much you could apply in the next week.

7. Plan for down time and field operations then schedule the next application.

8. Measure your actual applications. Application Efficiency varies greatly.

9. Don't try to plan too far in advance; it usually just doesn't work out.

10. Repeat the above steps over & over, making notes about how close your predictions were and why you think you missed the mark.

11. The most important thing is to keep at it. If you miss a week; don't give up; get out there and measure your soil moisture levels, you will learn something each time you do it.

Tools you need to carry-out the Above Plan:

- ☐ Soil Auger
- ☐ Alberta Agriculture Field Book
- ☐ Calculator
- ☐ Clip Board
- ☐ Rain Gauges
- ☐ Rubber Boots
- ☐ Alarm Clock

Some Ugly Truths about Irrigation Farming in Southern Alberta:
(Things you already know, but would like to ignore)

1. The rain you are betting on to save your crop likely won't materialize. Who predicts the weather in Southern Alberta?

2. Standard Crop use data is "budget data" in reality actual crop use can vary from these figures. Canola and Alfalfa have been measured to use 10mm per day in some situations, don't bank on crop use below the long term averages, it happens, but if it doesn't; you lose big time.

3. Technology won't compensate for lack of management. You can buy management help, but it doesn't have rubber tires.

4. The situations where we over apply are very rare, due to energy costs and other farming activities; most farmers under irrigate. You will need to work harder at irrigating.

5. Site Specific tools (where you bury something in one location) do not work as well here as most places in the U.S. due to the high variability of our soils. This fact requires us to cruise the field; this sounds like work! The good news is you learn other things about your crop when you walk around.

6. Saving on energy bills by pulling back on irrigations is false economy.

7. The wind sometimes blows in Southern Alberta. You may be getting far less into the soil reservoir that you think.

Still Unsure?
Invest in some professional advice.

WATER MANAGEMENT RESEARCH OF DRY BEANS IN SOUTHERN ALBERTA

Alan Efetha[1], Ted Harms[2], Ron Howard[2], Manjula Bandara[2], and Scott Meers[2]

ABSTRACT

The important decision as to when and how much water to apply and what irrigation management root zone to use in managing irrigation water on dry bean is essential for achieving high dry bean seed yield and quality. Research-based information on this issue is missing in Alberta. This study, therefore, was initiated to come up with the best irrigation water management root zone and application amount for the best irrigation management practice for dry bean in southern Alberta. The study took place near Bow Island for three years. The traditional 60-cm root zone recommendation for irrigation management was compared with other irrigation regimes. The results indicated that the traditional 60-cm irrigation management root zone treatment had lower seed yield in all three years than the other irrigation management regimes. The 30-cm root zone treatment and the 30-cm root zone at juvenile and then increase to 60-cm root zone at flower treatment yielded higher seeds than the other irrigation management treatments in all three years.

INTRODUCTION

Irrigated dry bean (Phaseolus vulgaris (L.)) production in Alberta increased from 15,000 ha in 1998 to 20,000 ha in 1999 and is currently at 23,000 ha, with a farm gate value in excess of $25,000,000. The worth of processing and value added for beans in Alberta for 2001 was $43,000,000.

Pulse Canada predicts the dry bean seeded area in Canada will double in the next five years. Both Manitoba and Saskatchewan have already taken initiatives for such expansion. Alberta Pulse Growers believe there is potential to grow up to 34,000 ha of beans in Alberta. Agricore United indicated that Alberta is a significant player in the market classes of beans it produces and that Alberta's market share has grown during the past five years. Dry bean acreage expansion depends on the development of proper irrigation management practices that are suitable for Alberta and western Canada's growing conditions.

Beans obtain 85% of their moisture from the upper 40 cm of the soil profile (Yonts and Nuland (1997). Soil moisture management for a root zone deeper than 50 cm would not be efficient when growing dry beans. Beans are also quite sensitive to soil moisture deficits. Faria et al. (1997) compared dry bean yield with various soil moisture deficits. They found that a significant decrease in yield was realized when soil moisture was

allowed to drop to 40% of available. Their recommendation was that soil moisture not be allowed to drop below 60% of available.

Heineman et al. (2000) evaluated irrigation application amounts and soil moisture deficits with the fluctuating prices of dry beans. They compared various pivot capacities (5 mm d^{-1}, 6 mm d^{-1} and 7 mm d^{-1}) with starting soil moisture deficits of 20, 30, and 40% to low, medium, and high commodity prices. Simulation results showed that there were not large differences between applying 7 mm d^{-1}, setting the pivot to complete a revolution in a day, compared to applying 7 mm d^{-1} and taking 3 days to complete a revolution (21 mm gross application). They concluded that the most economical irrigation management regime, yielding the greatest returns, occurred when application amounts of 6 mm d^{-1} were applied when soil moisture dropped to 70% of available in the top 30 cm of the soil profile. Carlesso et al. (2000) concluded that the optimal application depth was 30 mm for maximum dry bean production. They also found that changing the application depths later after plant antithesis increased plant height and leaf area index. Yonts and Nuland (1997) suggested that yields could be increased with light, more frequent irrigations.

Effective irrigation management of dry bean has never been studied in Alberta. The overall aim of this study is to provide experimentally and locally determined information on optimum root zone and the optimum irrigation application amount for economic production of dry bean in Alberta.

The specific objectives of this research study were:

a) To determine the depth to which soil moisture should be monitored for making decisions on irrigation management for efficient use of irrigation water; and
b) To determine the most beneficial irrigation application amount for dry beans.

MATERIALS AND METHODS

Experimental Site Description

The study areas in 2005, 2006, and 2007 were set up at the Alberta Agriculture and Food Crop Diversification Centre South sub-station about 22 kilometers south of the town of Bow Island, Alberta. The dry beans in all three years followed wheat in a rotation. The soils of the area are classified as Orthic Brown Chernozem, belonging to a complex of Bingville and Cranford soil series (CAESA-Soil Inventory Project Working Group 1998). The surface soil texture ranges from sandy loam to sandy clay loam, with a measured surface (60 cm depth) pH of about 7.2, electrical conductivity (EC) of 0.8 dS m^{-1}, and sodium adsorption ratio (SAR) of 1.4.

Field Operations

The study sites selected in 2005, 2006, and 2007 were deep ripped in the fall of 2004, 2005, and 2006, respectively. Soil samples were taken for macro-nutrient and zinc analyses. Salinity mapping of the sites was done using the EM38. The EM38 results in

all three years showed that the sites had salinity levels that would not limit bean growth. The soils were tilled using a deep ripper, a primary tillage implement, right after EM38 measurements had been completed. A vibrashank, a secondary tillage implement, was used for initial seedbed preparation in 2005, 2006, and 2007. Soil samples were taken for soil water holding capacity and soil fertility level determinations in the middle of April. Glyphosate herbicide was applied within the first week of May at a rate of 2.5 L ha^{-1} after weeds had emerged. Ethalfluralin herbicide (20 kg ha^{-1}), nitrogen (112 kg ha^{-1}), phosphorus (22 kg ha^{-1}) and zinc (5.6 kg ha^{-1}) fertilizers were broadcast and incorporated during the second week in May. The entire study area was then irrigated with 22 mm of water in the middle of May to provide adequate seedbed moisture. Light tillage was performed to prepare the seedbed prior to seeding treated Othello Pinto bean on May 25, 2005, May 27, 2006, and May 19, 2007. Dry beans were seeded at a target rate of 93,000 plants per acre for the entire study area with a 56-cm row spacing bean planter. Light irrigation (22 mm) was applied in 2005, 2006, and 2007 to the entire study area after seeding to ensure adequate soil moisture for seed germination.

By June 6, 2005, June 4, 2006, and June 2, 2007, the bean plants had fully emerged. The emergence measurements in all three years show the entire area had acceptable and uniform emergence, averaging 13 plants per linear meter. The study area had a low weed density. Nevertheless, a post-emergence herbicide, Bentazon, was applied on June 25, 2005, June 30, 2006, and June 20, 2007, at a rate of 2.2 L ha^{-1} using 38-L nozzles. The persistent weeds were controlled using between-the-row cultivation in early July. A post-emergence grassy weed herbicide, Sethoxydim, was applied at a rate of 2.2 L ha^{-1} in the second week of July followed by between-the-row mechanical weed removal. All of the liquid pesticides used in this project were applied at a high water volume (greater than 38 L ha^{-1}). The first flowers appeared at the end of the second week of July in all three years. Boscalid, a fungicide, was applied on July 18 and 30, 2005, on July 14 and 24, 2006, and on July 13, 2007, according to the manufacturer's labels and published recommendations (Alberta Agriculture and Food 2006). Scouting for pests was done once a week during the growing season. Agronomic notes were taken on emergence, plant population densities, flowering, and physical maturity. Reservoir tillage was performed once each year to prevent runoff. Sampling for disease and insect incidence and damage was done several times during the growing season in all three years. The bean plants in the entire study area were undercut on September 2, 2005, August 23, 2006, and August 28, 2007, after all the plots had reached physical maturity. The plots were harvested on September 21, 2005, and September 7, 2006, and September 10, 2007 using a small Hege plot combine (Wintersteiger). The harvested seeds were cleaned and weighed for yield determination.

Irrigation Treatments

Aluminum risers equipped with a Nelson R2000 full circle spray head sprinkler, pressure regulator, and shut-off valve were installed in the four corners of each plot. Soil moisture access tubes were installed in the center of each plot and the first soil moisture readings were taken on June 14, 2005, June 9, 2006 and June 12, 2007. Soil moisture

readings were taken twice a week until the crop matured. A TRIME T3-50 TDR tube soil moisture probe was used to determine soil moisture at 20-cm depth intervals to a depth of 120 cm. Initial soil hydrologic properties were determined using a pedo-transfer function based on the soil texture of each plot (Saxton 1981) and were adjusted in early June after a major rainfall event coupled with irrigation.

The following irrigation management treatments were implemented:

1. Maintain soil moisture above 60% of available soil moisture in a 60 cm root zone. This is the common method of irrigation management in Alberta. **Abbreviated as: 0-60 cm**

2. Maintain soil moisture above 60% of available soil moisture in a 30 cm root zone. This is practiced in other places in the world and results in more water being applied frequently. **Abbreviated as: 0-30 cm**

3. Vary root zone with plant growth stages: Maintain soil moisture above 60% of available soil moisture in a 30 cm root zone during juvenile growth stages and maintain soil moisture above 60% of available soil moisture in a 60 cm-root zone during flowering, pod set, and at the start of maturity. The logic with this treatment is to put water where the roots are. Roots are shallow during vegetative stages and elongate once flowering commences. **Abbreviated as: Split 30/60 cm**

4. Apply 12 mm per irrigation event to maintain soil moisture above 60% of available soil moisture within a 60 cm root zone. Every time soil moisture drops to 60% of available, an irrigation amount of 12 mm is applied. This results in frequent irrigation events. **Abbreviated as: 12 mm**

5. Apply 25 mm per irrigation event to maintain soil moisture above 60% of available soil moisture within a 60 cm root zone. Every time soil moisture drops to 60% of available, an irrigation amount of 25 mm is applied. This represents what most irrigators with center pivot sprinkler systems normally apply during the growing season. **Abbreviated as: 25 mm**

6. Apply 50 mm per irrigation event to maintain soil moisture above 60% of available soil moisture within 60 cm root zone. Every time soil moisture drops to 60% of available, an irrigation amount of 50 mm is applied. **Abbreviated as: 50 mm**

The above six irrigation treatments with four replications were arranged in a randomized complete block design (RCBD). The dimensions of each plot were 6.1 m x 6.1 m with a buffer of 12.2 m to minimize treatment crossover. The soil moisture was monitored twice

a week using a TRIME T3-50 TDR tube and, if irrigation was needed, the treatments were applied accordingly.

Statistics

The General Linear Model (GLM) and MEANS procedures in SAS/STAT™ (SAS Institute Inc. 1996) were used for statistical analyses and data reduction, respectively. The Tukey multiple mean comparison test was used for mean separation.

RESULTS AND DISCUSSION

Meteorological Observations

Seasonal rainfall, temperature, and corn heat units compared to the 30-year normal are shown in Table 1. Above normal precipitation in June and below normal temperatures in most months resulted in a reduction of corn heat units in 2005 compared to almost normal in 2006 and 2007. The 2005, 2006, and 2007 growing seasons were favorable for dry bean production in the Bow Island area. Climatic conditions in 2006 seemed to favor fungal disease growth in the entire Bow Island area.

Table 1. Meteorological data from the Alberta Agriculture and Food Bow Island Sub-Station.

Year		Month				
		May	**June**	**July**	**August**	**September**
2005	Rainfall (mm)	8	150	1.6	49	61
	Average Temperature (^{0}C)	12	15	19	16	12
	Corn Heat Units (CHU)	241	518	628	545	291
2006	Rainfall (mm)	35	97	0	2	10
	Average Temperature (^{0}C)	13	18	21	18	13
	Corn Heat Units (CHU)	290	593	739	630	386
2007	Rainfall (mm)	61	58	2.2	18	35
	Average Temperature (^{0}C)	12	17	23	18	12
	Corn Heat Units	198	575	766	633	353
30-year normal	Rainfall (mm)	17	52	43	35	19
	Average Temperature (^{0}C)	13	17	19	19	13
	Corn Heat Units	277	602	695	666	424

Note: Corn heat units are calculated from May 15 until the first killing frost (-2^{0}C).

The climatic conditions in 2005 and 2007 did not favor fungal disease development. The average temperature in July in 2007 was higher than normal and the previous years of study (Table 1).

Crop Yield

The crop canopy was heavier in 2007 and 2006 than in 2005. The rows closed in faster in 2007 and 2006 than in 2005, resulting in thick stands. The quick growth could be attributed to greater cumulative corn heat units and higher average temperatures in 2007 and 2006 than in 2005 (Table 1). Based on the thick stand observed, the hot climatic conditions, and favorable dry bean growing conditions, the 2006 and 2007 potential yields were expected to be higher than that of 2005. The presence of fungal disease in all plots in 2006 affected yields in 2006. The bean crop in 2007 was free of fungal diseases and therefore the expected yield results were similar to the actual (Fig.1).

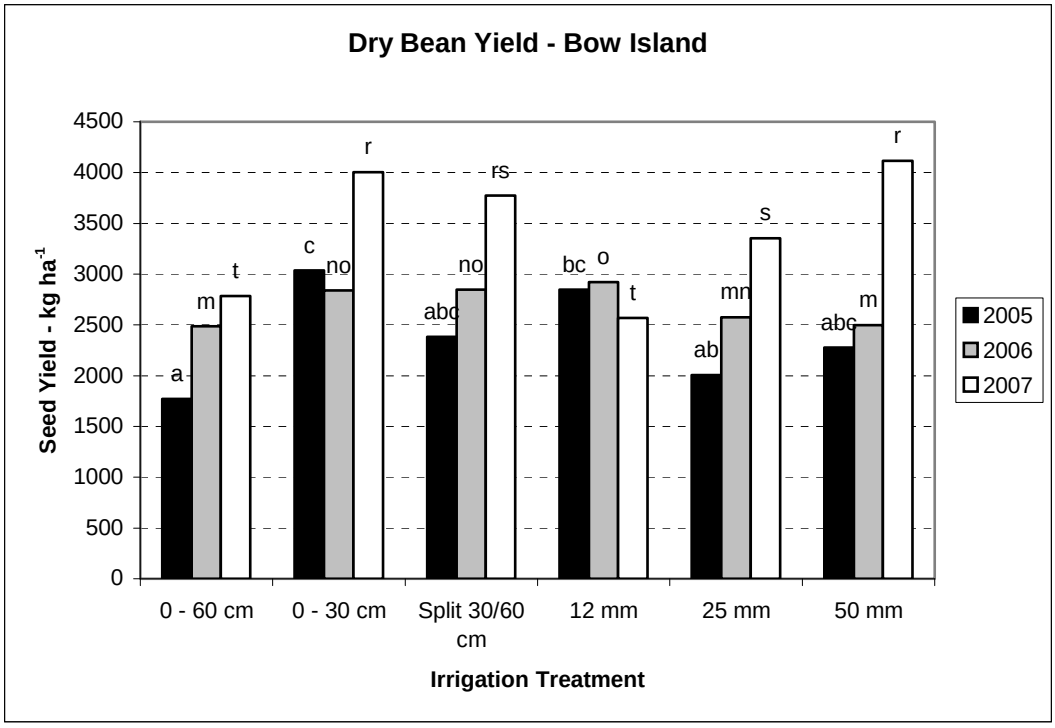

Fig. 1. The impact of varying irrigation management root zone and irrigation water application amount on dry bean seed yield for all treatments at Bow Island in 2005, 2006 and 2007. Values for each year with the same letters are not significantly different *(P<0.05).*

In both 2005 and 2007 the plots were free of diseases. The highest average yield in 2007 was higher than the average yield in 2006 and 2005. The yield values ranged from 1770 kg ha^{-1} to 3036 kg ha^{-1} in 2005, from 2486 kg ha^{-1} to 2924 kg ha^{-1} in 2006, and 2268 kg ha^{-1} to 4117 kg ha^{-1} in 2007 (Fig. 2). The higher average yield in 2007 could have been due to the higher temperatures in July as compared to July temperatures in 2005 and 2006.

The shallow root zone treatments (30-cm root zone) gave significantly higher yield than the 60-cm root zone and the 25-mm application treatments in 2005 (Fig. 2). The frequently irrigated treatments (12-mm application) resulted in significantly greater bean seed yield than the longer scheduling interval treatments (60-cm root zone, 25-mm and 50-mm application) in 2006. The top yielding treatments in 2007 were the 30-cm root zone and the 50-mm application treatments followed by the split 30/60-cm root zone treatment. Over the three years, treatments 2 (30-cm root zone) and 3 (split 30/60-cm root zone) had consistently higher seed yields than the other treatments. The 12-mm application treatment had reasonable seed yield during the first two years when the temperatures in July were average but when the July temperatures and corn heat units increased in 2007 the light applications could not keep up with the bean crop water demand during peak demand. As a result the maturity was prolonged and yield reduced. The reason for the different findings with the split treatment between the two years is not clear. The general finding of shallow root zone treatments yielding higher than the deep root zone treatments is consistent over the three years. These findings indicate that the highest percentage of water used by the dry bean crop came from the top portion of the root zone; therefore, if water is readily available in this zone, especially when the crop is in the vegetative growth stage, higher yield will result.

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Thanks to conference sponsors Sandberg Laboratories and