SUSTAINABLE PRODUCTION OF

DURUM WHEAT IN CANADA

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The purpose of the durum production manual is to promote sustainable production of durum wheat on the Canadian prairies and enable Canada to provide a consistent and increased supply of durum wheat with high quality to international and domestic markets.

TABLE OF CONTENTS

PLANNING

PEST MANAGEMENT

HARVESTING TO MARKETING

To access all of the content throughout this publication, please ensure you have downloaded Adobe Reader 11.0.23 or higher.

1. INTRODUCTION: RESPECTING THE CONSUMER AND THE ENVIRONMENT

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Wheat and wheat products provide about 20% of protein and calories consumed per capita.

Durum wheat is a premium class of wheat used primarily for making food products such as pasta, couscous, and bulgur. Pasta products are very popular around the world whereas couscous and bulgur are popular in regions such as North Africa. To meet consumer expectations, premium pasta requires durum wheat grain with high protein content, strong gluten strength, and bright yellow pigment content.

The global human population is projected to reach 9.7 billion by 2050. Wheat and wheat products provide about 20% of protein and calories consumed per capita (CRP WHEAT, 2016). Projections regarding wheat growth demand to 2050 vary widely around an average of about 50% from the 2010 level. Higher crop yields require higher inputs such as organic and inorganic fertilizers that emit greenhouse gases with significant environmental impacts. Durum wheat is one such crop that requires large fertilizer input due to the high protein concentration in the grain. More than 50% of the environmental impact of producing a pasta product arises directly from grain cultivation at the farm gate. Consequently, durum wheat production challenges to meet food security include cropping systems and environmental sustainability.

What efforts can be taken to help drive the 'decoupling' of crop yield increases from the greenhouse gas footprints in the production of durum wheat crops? Can durum wheat crop yields be increased to narrow the gap between potential and current yields while concurrently decreasing the greenhouse gas footprint? To do so, we must continue to develop new production technologies and implement a sustainable production system at the farm gate.

This Durum Production Manual aims to provide best management principles, practices and resources to contribute to sustainability and profitability for the long term. The focus of the Durum Production Manual is to produce durum wheat in an environmentally sustainable manner, including respect for the environment for future use by others. Yet, the production must be done in a manner that is profitable so that farmers have an economic activity that exceeds their opportunity costs. The durum wheat produced is a foundational ingredient in the production of food as pasta, semolina, couscous and other food products. Consumers have high expectations of the production of food that is nutritious. When agricultural production meets these expectations, society grants a social license. The challenge is to think long term: "Good for You. Good for the Community. Good for the Planet."

Reference

CRP WHEAT (2016) Wheat agri-food systems proposal 2017-2022. CGIAR. Research program on Wheat. Pp 273

2. DURUM PRODUCTION AND CONSUMPTION, A GLOBAL PERSPECTIVE

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Global Durum Supply

Total world wheat production in 2018/19 is forecasted to be 716.4 million tonnes (MT) down from the projected production of 758.0 MT in 2017/18 (International Grains Council, 2018). This includes production of all wheats including durum wheat. Global durum wheat production for 2016/17 was 39.942 MT (Table 1; IGC, 2017) and this typically represents 5% of total wheat production. Globally, durum is planted on over 16 M hectares.

Major Durum Producing Countries

Durum wheat is grown in many of the same countries that produce common wheat. This includes countries within the European Union (EU), Commonwealth of Independent States (CIS), North America, South America, Asia, Africa and Oceania (Table 1). However, the majority of durum wheat production is within North America, with durum production in Canada (about 7.8 MT) being almost three times the production of the United States (US) and Mexico (Figure 1). Other notable durum producing countries include Italy (4.950 MT) and Turkey (3.62 MT) (Figure 1; IGC, 2017). In Canada, durum wheat is primarily grown in southern Saskatchewan, with some production in south eastern Alberta (Figures 2 and 3). Because diseases such as Fusarium head blight occur frequently in Manitoba, little to no durum is grown there.

Durum wheat in Canada is referred to by its market classification as CWAD (Canada Western Amber Durum). The Canadian Grain Commission (CGC) is responsible for establishing and maintaining the grading standards for a number of grains grown in Canada. For CWAD there are five milling grades (No. 1 through No. 5; CGC, 2017a).

Durum wheat production in Canada for 2017/18 was 4.96 MT, which was a 36% drop from record production levels observed in 2016/17 (Statistics Canada, 2018). The reason for this drop was due to fewer seeded acres and lower precipitation which resulted in decreased yields. However, for 2018/19, durum wheat production in Canada is forecasted to reach 5.71 MT, which is a 15% increase over 2017/18 production (Statistics Canada, 2018). This rise in production is driven by an increase in seeded acres.

Total global trade in durum wheat has varied from 7.4 MT to 9.3 MT during the period 2011/12 to 2015/16. The top ten countries for Canadian durum wheat exports are shown in Table 2 along with their 5-year averages. Canada is a regarded as a producer of high quality durum wheat that is highly desired around the world for a number of reasons.

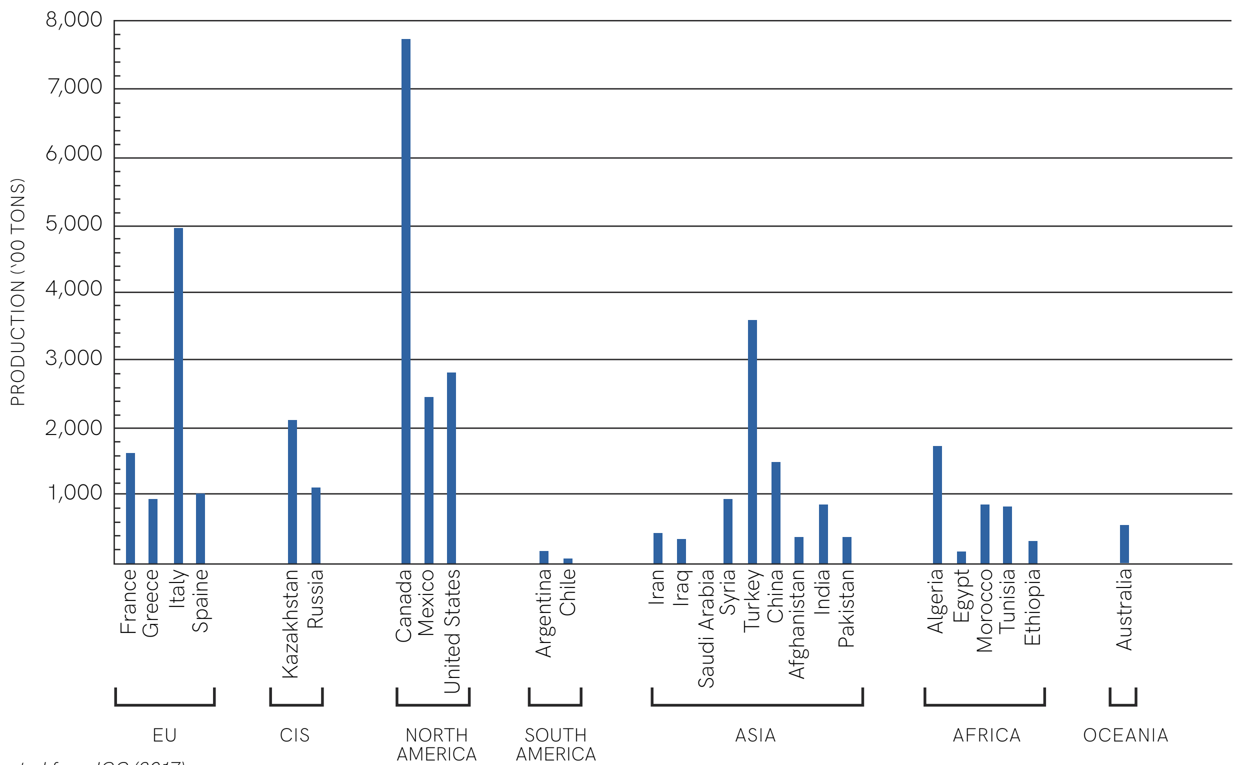
TABLE 1. *Durum Production ('000 tons) from 2007/08 to 2016/17 (July/June)[1]*

REGION	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Europe[2]	8,227	10,053	8,748	9,177	8,219	8,164	8,133	7,641	8,494	9,361
CIS	5,340	5,915	4,900	3,450	5,100	3,000	4,100	4,000	4,100	4,190
North America	7,432	9,709	10,456	7,987	7,652	8,945	10,383	8,914	9,925	13,061
South America	189	191	155	248	238	164	182	268	305	230
Asia	8,559	7,742	9,340	9,150	9,880	9,260	9,905	8,570	9,810	8,520
Africa	4,748	4,483	7,282	4,870	5,900	5,750	5,690	4,600	5,962	4,030
Oceania	300	450	500	500	600	450	450	470	480	550
World Total	34,795	38,543	41,381	35,382	37,589	35,733	38,843	34,463	39,076	39,942

[1]Adapted from IGC (2017)
[2]EU (27) from 2007/08. EU (28) from 2013/14.

The variety development and registration process in Canada has ensured that developments in CWAD have focused not only on increased productivity and disease resistance but also on processing requirements such as increased protein content, improved protein quality (gluten strength), and increased yellow pigment content (carotenoids) among other quality improvements.

Canada leads the world in durum wheat exports, with about half of all durum wheat available for export grown in Canada (Figure 4). Mexico and the EU provide 17% and 16%, respectively. Other countries that also export durum wheat include the U.S.A., Australia, Mexico and Kazakhstan.



[1]Adapted from IGC (2017)

FIGURE 1. *Durum Producing Countries by Region for 2015/16 (July/June)[1]*

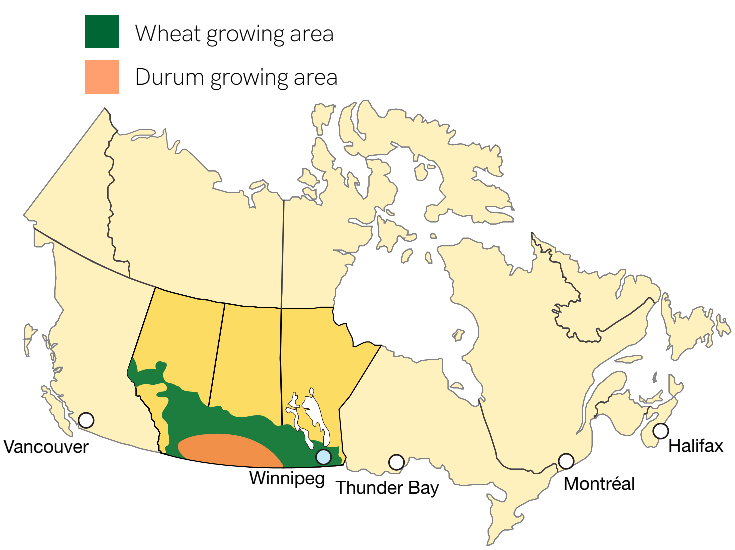
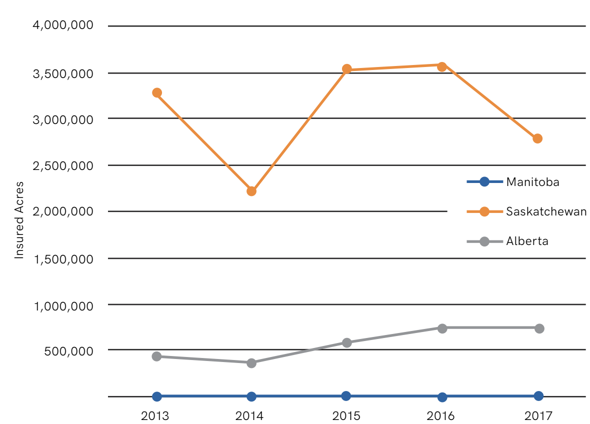


FIGURE 2. *Map of the Wheat and Durum Wheat Producing Areas in Canada*



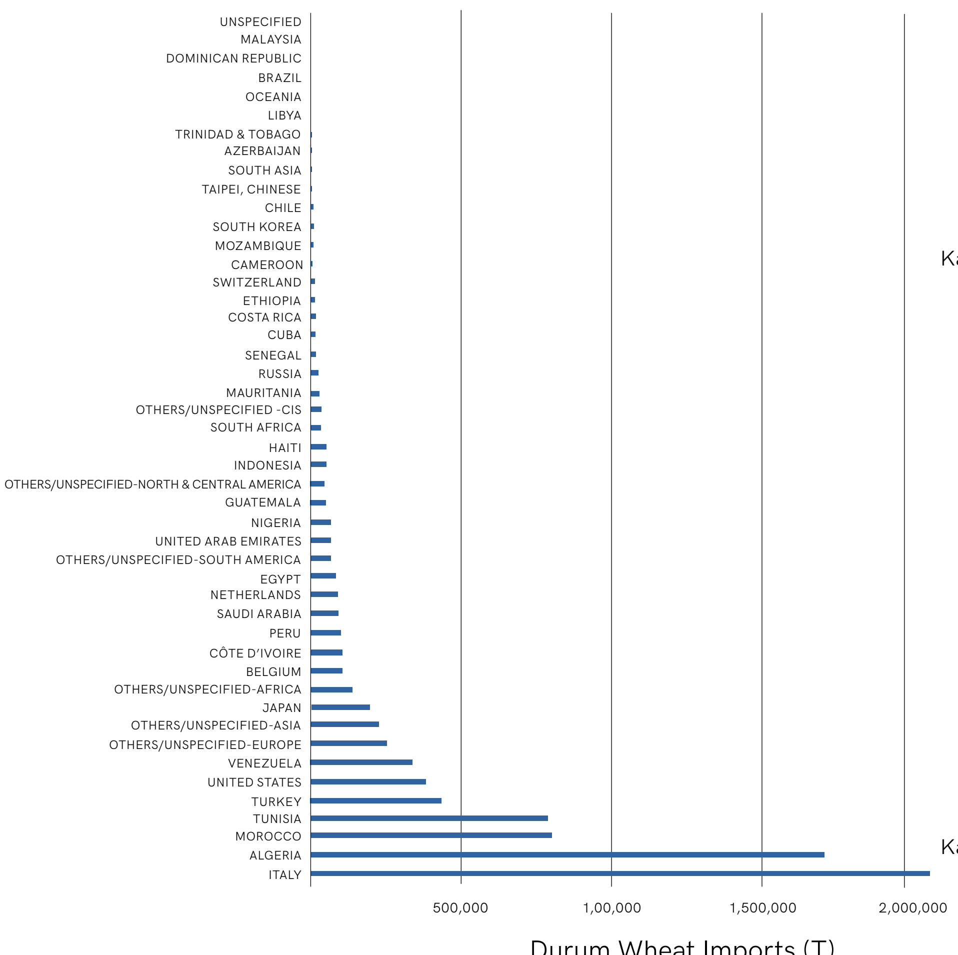
[1]Insured acres by provincial crop insurance agencies and is typically about 70% of total acres planted.
[2]Adapted from CGC (2017b).

FIGURE 3. *Insured[1] Acres of CWAD in Canada (2013-2017)[2]*

TABLE 2. *Top 10 Countries for Canadian Durum Wheat Exports ('000 MT) from 2013/14 to 2017/18 (August/July)[1]*

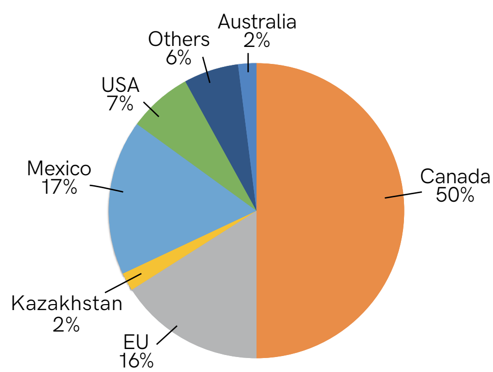
COUNTRY	2013/14	2014/15	2015/16	2016/17	2017/18	5-YEAR AVERAGE
Italy	987.3	1415.7	1211.3	732.0	386.9	946.6
Algeria	649.7	821.1	977.6	1265.0	1025.8	947.8
Morocco	736.7	528.6	599.1	686.3	838.3	677.8
United States	521.4	239.3	145.5	208.5	752.8	373.5
Venezuela	447.0	256.0	98.0	59.9	41.9	180.6
Belgium	234.3	329.9	132.2	133.2	37.4	173.4
Japan	224.8	231.6	172.5	230.7	172.9	206.5
Tunisia	257.5	34.0	283.1	48.5	23.6	129.3
Peru	144.4	128.2	110.7	131.1	181.1	139.1
Turkey	105.8	82.7	138.5	127.1	49.5	100.7
Total Canadian durum exports	4824.9	4606.1	4361.6	4290.2	3939.9	4404.5

[1]Adapted from CGC (2018).



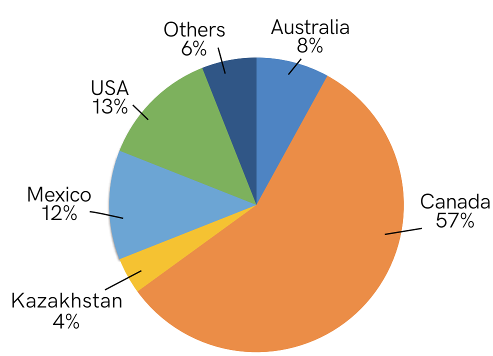
[1]Adapted from IGC (2017)

FIGURE 5. *Countries Importing Durum Wheat During 2015/16 (July/June)[1]*



[1]Adapted from IGC (2017).

FIGURE 4. *Top Exporters of Durum Wheat for 2015/16 (July/June)1 (Total world exports of 8.7 million tonnes)*



[1]Adapted from IGC (2017).

FIGURE 6. *Comparison of Durum Wheat Imports into Italy for 2015/16 (July/June)[1]*

Major Buyers of Durum

The largest buyer/importer of durum wheat is Italy with imports for 2015/16 totaling approximately 2.05 MT (IGC, 2017; Figure 5). Other notable importers of durum wheat include the North African countries of Algeria, Morocco and Tunisia. Canadian durum wheat provides more than half of Italy's import needs (1.16 MT), while remaining imports are from the U.S., Mexico, Australia and Kazakhstan (Figure 6). However, markets continuously change, at the time of writing Italy has significantly decreased imports of Canadian durum and growth in other markets has occurred.

Uses of Durum around the world

Durum wheat is used primarily for the production of pasta and to a limited extent, couscous. Pasta has great popularity over much of the world, while the popularity of couscous is more regional, with consumption is highest in North African and Middle Eastern countries. While pasta and couscous are different, they both use durum semolina for their production. Semolina is milled from durum wheat into a coarse granular material with a particle size generally greater than 150 microns (μm). The hard texture of the durum wheat kernel makes it well suited for the production of semolina.

Pasta has been consumed for a long time. Pasta did not likely originate in Italy, but rather Marco Polo is alleged to have brought Asian noodles to Italy in the 13th century. History records also indicate that pasta was likely eaten even earlier than this time, produced from a mixture of ground wheat and water that was developed into a dough, left to dry, and be cooked at a later time.

Although pasta and Asian noodles may share similar shapes they are different products that have different ingredients and processing requirements. Whereas noodles are made from wheat flour, water and salt (or alkaline salts, depending on the noodle type), mixed, sheeted, and then cut, pasta is made from durum semolina and water which is mixed under vacuum and then extruded through a die into various shapes and then dried. Pasta can be made with flour milled from common wheat.

However, some countries such as Italy have regulatory Standards of Identity that specify that in order for the product to be called pasta it must be to be made with 100% durum semolina. High quality durum wheat semolina will be high in the pigment beta-carotene, which provides the characteristic yellowness that is expected from pasta.

TABLE 4. *Top 20 Countries for World Pasta Consumption*[1]

COUNTRY	kg PER CAPITA	COUNTRY	kg PER CAPITA
Italy	25.3	France	8.1
Tunisia	16.0	Germany	8.0
Venezuela	12.2	Russia	8.0
Greece	11.5	Uruguay	7.5
Switzerland	9.2	Croatia	7.5
United States	8.8	Sweden	7.0
Iran	8.5	Turkey	6.8
Chile	8.4	Portugal	6.7
Argentina	8.3	Canada	6.5
Peru	8.2	Hungary	6.4

[1]*Adapted from IPO (2014).*

FIGURE 7. *Traditional Serving of Couscous with Vegetables.*

FIGURE 8. *Making super long pasta with Canadian Semolina. Photo Credit: R.M. DePauw*

Countries that produce pasta from common wheat flour include countries in South America and West Africa. In these countries, the price of durum wheat may be cost-prohibitive thereby preventing its use, and/or consumers may not have a preference for pasta with a bright yellow colour.

Recent developments in pasta processing include the use of high speed mixing, such as Bühler's Polymatik pasta press, and high temperature drying (HTD), compared to conventional or low temperature drying. High speed mixing, allows for greater processing efficiencies and better retention of yellow colour in the dried pasta. HTD generally refers to drying temperatures greater than 60°C. HTD also allows for improved processing efficiency, but the main advantage of HTD is improved cooking quality and colour retention.

According to the International Pasta Organisation (IPO), the top three countries in per capita (kg) consumption of pasta in 2014 were Italy, followed by Tunisia and Venezuela (Table 4). In North American, per capita pasta consumption is higher in the United States than Canada. The popularity of low carbohydrate diets and an increasing focus by consumers on gluten-free diets in many countries around the world has threatened pasta consumption.

Couscous is more commonly consumed in North African and Middle Eastern countries and would be considered a traditional dish in these countries. Couscous is produced from durum semolina that is steamed, causing the agglomeration of semolina particles, dried, cooled and then sized (sorted). Couscous sold in Morocco is shown in Figure 7. The dried couscous is then rehydrated by steaming and served with meat and vegetables (Figure 8).

Although couscous has traditionally been produced at home, industrial couscous production has become more common in these countries.

Other foods produced from durum wheat include bread, bulgur, freekeh, and puffed cereal. Production of bread made from durum wheat typically uses durum flour and not semolina. This type of bread is popular in the southern region of Italy and has been referred to as Altamura bread (Figure 9).

FIGURE 9. *Bread made from Durum Flour.*

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Canadian Grain Commission. 2017a. Official Grain Grading Guide. Available on-line at http://www.grainscanada.gc.ca/oggg-gocg/ggg-gcg-eng.htm (accessed January 5, 2018).

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3. VARIETY SELECTION TO MEET FARMER PROFITABILITY

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Producers have an array of durum wheat varieties to choose from in the Canada Western Amber Durum (CWAD) market class, which requires that careful consideration be given to the selection of genetics that will perform best in the intended environment. Durum wheat varieties not only differ in their agronomic traits, but also in their response to diseases and insects. Even though all durum varieties are eligible for grades of CWAD, there are subtle differences among varieties in end-use traits such as quantity of protein, pigment content, and semolina yield.

Choice of variety can impact grain yield, grain quality, and the type of management practices that might be needed to optimize performance and profitability for a given environment. This is described as Variety x Management x Environment interaction. Consequently, the choice of variety should consider the strengths and weaknesses of each variety, the production practices that will be applied, and the expected moisture available for growing a crop. For example, the choice of variety for irrigation would put a much greater emphasis on straw strength than an environment known to have a high frequency of heat and drought stress.

This section will explain some considerations to select a variety to meet the on-farm production constraints, and how to target the market place to deliver a premium product that enables processors to manufacture food products to meet consumer expectations. Durum varieties don't just happen. They result from a very deliberate process. Plant breeders recombine genes from different parents to improve production traits, disease and insect resistance, and grain quality traits. These new experimental lines are evaluated relative to the producer and industry standards to measure improvements.

Photo credit: SOUTH WEST TERMINALS

Experimental durum wheat lines are evaluated for their agronomic performance and resistance to diseases and insects by the Prairie Recommending Committee of Wheat Rye and Triticale (PRCWRT) (http://www.pgdc.ca/committees_wrt.html) under authority of the Canadian Food Inspection Agency (CFIA). Varieties supported for registration may be registered for growing in Canada.

Since 2010, 22 new varieties have been released which is more than in the previous 25 year period! Grain yield and protein content relative to the industry standard check variety, Strongfield, and key traits of these new varieties are listed in Table 1. The latest description of durum varieties is available at websites listed in the webliography. Producers are encouraged to use a combination of the Canadian Food Inspection Agency's List of Registered Varieties, http://www.inspection.gc.ca/, and the Canadian Grains Commission's Variety Designation Lists, http://www.grainscanada.gc.ca/, to determine the registration and grade eligibility status of varieties.

Grain Yield

When studying a variety for its yield potential, the most reliable indicator of future performance is past performance measured in replicated multi-location and multi-year trials. After a variety has been registered, it is grown annually in regional performance trials in each of the prairie provinces at 10 to 12 locations to determine its regional performance. Grain yield, protein content, time to maturity, seed weight, volume weight, and plant height of all durum wheat varieties are compared to a check variety, which at the time of writing is Strongfield. Not all varieties are grown together every year. Varieties are tested for five years. Therefore, varieties are compared directly only to the check variety, Strongfield. Comparison of one variety to another variety can only be done indirectly through the check, Strongfield. For example, if variety AB yields 5% more than Strongfield and a second variety, BZ, yields 7% more than Strongfield, but these two varieties were not trialed in the same tests in the same years, then the comparison would be indirect and the difference between the two varieties may not be a real reliable difference. By the time a variety has been tested in regional trials for four or five years, its performance as listed in the Seed Guide is a reasonably sound indicator of its future performance, relative to the check, Strongfield. Traits other than grain yield should also be considered when choosing a variety to grow. For example, plant height and straw strength are important considerations when targeting high inputs of water and nutrients.

Disease and Insect Resistance

Generally, when selecting a variety, people give most weight to grain yield. However, it is important to consider disease and insect factors to protect grain yield and end-use quality. Response to diseases of all varieties are listed in the provincial seed guides. Fusarium head blight (FHB) has become the most devastating disease of durum as it not only reduces grain yield but also reduces the quality of the grain and produces mycotoxins (e.g., deoxynivalenol or DON) which is harmful to humans and animals. The FHB rating of all varieties is listed in the Seed Guides. Currently, durum wheat varieties have less genetic resistance than that available in spring wheat. The best strategy to combat FHB is an integrated approach that combines genetic resistance, with management that includes proper fungicide selection, timing with appropriate application technology, FHB disease forecasting, and crop rotation. (Disease Control Section)

Most varieties are resistant (R) to moderately resistant (MR) to leaf rust, stem rust, stripe rust, and common bunt. If a variety is susceptible (S) to moderately susceptible (MS) to loose smut, it is advisable to purchase certified seed that has a seed treatment to control loose smut. Thereafter, monitor the variety after heading for symptoms of loose smut. Future seed treatment for loose smut would be advised only if loose smut was observed. Leaf spotting diseases, caused by tan spot and or Septoria, can cause grain yield loss and infect the kernels resulting in further loss of market value through down-grading (see Table 3 on price spreads among grades). Application of a fungicide for the control of leaf spotting is advisable when the revenue loss per acre from disease is anticipated to exceed the cost of control. See the disease control section. At the time of writing no durum variety is registered with resistance to ergot. But it is expected that ergot resistant varieties will become available.

Wheat stem sawfly and orange wheat blossom midge are economically important insects of durum. (Insects section). The solid stem trait confers resistance to the wheat stem sawfly not only in year one but also in year two. Sawfly larvae that have developed in a solid stem are reduced in size. A greater proportion of smaller larvae don't successfully overwinter compared to normal size larvae. Also, the fecundity (eggs per female) from these smaller larvae are less than from normal size larvae. Solid stem varieties are described in the provincial seed guides and Table 1.

Reduced damage to the kernel caused by the orange wheat blossom midge is conferred by the *Sm1* gene. (Insects' section). The midge reduces not only grain yield but also quality which results in loss of market value.

In a normal population of midge, the majority will be susceptible to the *Sm1* gene, however, a few mutants will survive on the *Sm1* gene. To protect the *Sm1* gene against mutant virulent midge overcoming the *Sm1* gene, a stewardship program has been implemented, using a variety blend (VB) of 90% of the tolerant variety (with the *Sm1* gene) and 10% of a susceptible refuge (without the *Sm1* gene). (http://www.midgetolerantwheat.ca/). Varieties with the variety blend are listed in the Seed Guide with a "VB" designation after the variety name and Table 1.

Grain Processing Quality

Canadian durum is a premium wheat class used primarily for making pasta products and couscous as well as other specialty products such a bread and confectionary items. The Canadian Grain Commission (CGC), operating under authority of the Canada Grain Act, establishes both market classes of grain and the grades within each class. For a variety to be eligible for grades of CWAD, it must be assessed for a minimum of three years by the Canadian Grain Commission under the categories of whole grain (Hagberg Falling Number, cadmium, and percentage hard vitreous kernels), milling performance (milling yield, semolina yield and semolina ash), protein content (whole grain and semolina), gluten strength (gluten index and alveograph), and semolina pigment and pasta colour (total yellow pigment, and colorimetric values for b* and a*). All durum varieties registered for cultivation in Canada are eligible for all grades of CWAD.

Based on research by the CGC, which establishes the relationship between grading factors and end-use quality, the CGC specifies both the grading factors and the protocols to measure the grading factor. https://www.grainscanada.gc.ca/oggg-gocg/ggg-gcg-eng.htm Primary grade determinants tables for Canada Western Amber Durum lists the levels acceptable for each grade.

THE GRAIN GRADING FACTORS BELOW ARE LISTED IN ALPHABETIC ORDER AND NOT BY IMPORTANCE:

- Artificial stain (ART STND)
- Degermed kernels (DGM)
- Ergot (ERG)
- Excreta (EXCR)
- Fireburnt kernels (FBNT)
- Frost/heat stress damage (FRHTS)
- Fusarium damage (FUS DMG)
- Grasshopper Armyworm damage (GAW)
- Green (GR) and Grass green kernels (GRASS GR)
- Hard vitreous and non-vitreous kernels
- Matter other than cereal grains (MOTCG)
- Heated (Binburnt, severely mildewed rotted, mouldy)
- Midge damage
    - Midge damage (MDGE DMG)
    - Severe midge damage (SEVMDGE)
- Mildew damage (MIL)
- Natural stain
- Pink kernels (PNK)
- Ruptured kernels (RUP)
- Sawfly damage (SFLY DMG)
- Sclerotinia (SCL)
- Shrunken (SHR) and Broken (BKN)
- Smudge and black point
- Stones (STNS)
- Sprout damage (SPTD) and severe sprout damage (SEVSPTD)
- Other cereal grain (OCG)
- Wheats of other classes or varieties (WOOC)

TABLE 1. *Varieties registered in Canada since 2010 eligible for grades of Canada Western Amber Durum, their yield difference as a percent of Strongfield, protein deviation from Strongfield, key beneficial traits and the year released for production.*

NAME	YIELD % STRONGFIELD IN DURUM AREA[1]	PROTEIN DEV STRONGFIELD[1] (%)	KEY TRAITS	YEAR
Transcend[2]	3.1	-0.3	improved FHB resistance[3], grade protection	2010
CDC Desire	1.0	-0.2	high grain pigment	2012
CDC Vivid	3.0	-0.3	high grain pigment, strong straw	2012
AAC Current	1.0	0.0	high test weight	2012
AAC Raymore	-5.0	0.2	solid stem, resistant to sawfly	2012
CDC Fortitude[4]	4.0	-0.2	solid stem, resistant to sawfly	2013
AAC Durafield	2.0	-0.2	semolina yield	2013
AAC Marchwell VB[5]	-1.0	-0.1	midge tolerant	2013
CDC Carbide VB	7.0	-0.2	midge tolerant	2014
AAC Cabri	5.0	-0.3	solid stem, resistant to sawfly	2014
AAC Spitfire	9.0	-0.5	high yellow pigment, strong straw	2014
CDC Precision	10.0	-0.6	high test weight	2015
CDC Dynamic	7.0	0.0	high test weight	2015
CDC Alloy	10.0	-0.4	high test weight	2015
AAC Congress	9.0	-0.5	semolina yield	2015
CDC Credence	6.0	-0.7	improved FHB resistance[3]	2016
AAC Stronghold	4.0	-0.4	very strong straw, solid stem, resistant to sawfly	2016
DT587[6]	8.0	-0.5		2017
AAC Succeed VB	4.0	-0.1	midge tolerant	2017
DT591	6.1	-0.2	imidazolinone tolerance	2018
DT878	9.5	-0.2	solid stem, resistant to sawfly	2018
DT881	9.9	-0.3	strong straw	2018

[1] Durum area is represented by Saskatchewan agro-ecological areas 1 and 2. Source: Varieties of Grain Crops 2018, Saskatchewan.
[2] All varieties from Transcend to AAC Raymore are protected by UPOV'78.
[3] Improved FHB within the moderately susceptible category.
[4] All varieties registered in 2013 and subsequently are protected by UPOV'91
[5] VB means a varietal blend of 90% Sm1 midge tolerant variety and 10% of a non Sm1 susceptible variety.
[6] Varieties with a DT designation have not been registered with CFIA at the time of printing.

The grading factors may be divided into those influenced by the variety i.e. genetic factors and by non-variety factors i.e. environmental factors. Down-grading causes significant economic loss. Dropping from #1 to #5 CWAD, results in almost $100 / t or about 1/3 of its value. The information on total payments by market class, grade within a class, and protein premiums is no longer disclosed. However, it is expected that the market place today functions in a similar manner.

Protein content is not a grading factor directly. Low protein content may be associated with non-vitreous kernels, which are called variously: non-vitreous kernels, starchy kernels, yellow berry or pie-bald kernels, which can result in lower semolina yield. Consequently, vitreous kernels are preferred over non-vitreous kernels. Both variety and environment determine levels of hard vitreous kernels. Premiums and discounts for protein content may be applied by the buyer (Table 2). CGC grade standards have higher requirements for vitreous kernels in CWAD than in other wheat classes, including CWRS.

Varieties differ in their ability to produce protein. Varieties are assessed for not only grain yield but also the protein content in the regional trials. Generally, as the grain yield increases the protein content declines relative to the check, Strongfield. The seed guides list both the protein production potential and the grain yield relative to the check, Strongfield.

Durum wheat varieties are very responsive to nitrogen fertilizer, if there is sufficient moisture. Grain yield and protein content are more highly influenced by nitrogen availability than other traits such as semolina yield, gluten strength, and pasta color.

Kernel bleaching and sprouting results in down grading and loss of value. Varieties rated as having good resistance to sprouting are less prone to bleaching and kernel sprouting compared to varieties rated poor.

Certified Seed

Marketing rights to a variety registered for growing in Canada are awarded to a seed company, generally, through a competitive request for proposals. The seed of the variety is then multiplied, promoted and distributed by the seed company to commercial farmers. Multiplication of the pedigreed seed follows standards set by the Canadian Seed Growers Association (http://seedgrowers.ca/) and requirements in the Seeds Act, and approved by CFIA. The provincial seed guides also list the breeding institution and the seed distributor for each variety. Certified seed guarantees the purest genetics, meaning the seed is assured to be of the named variety, germination level, and freedom from noxious weed seeds. However, the germination and vigour can be negatively influenced by such factors as FHB, DON, frost, and sprouting.

Plant Breeders Rights

Varieties may be protected under Plant Breeders Rights (PBR) UPOV78 and more recently by UPOV91 under the new PBR Act. Authorization is required to produce, reproduce, sell, clean/condition, stock, import or export seed of UPOV91 PBR-protected varieties. Proof of legitimately acquiring the seed of a protected variety is required for all subsequent utilization or processing of the variety. Everyone in the processing chain is now accountable under UPOV91.

In the provincial seed guides, varieties protected under UPOV78 have the symbol

and varieties protected under UPOV91 have the symbol.

Learn more at: http://pbrfacts.ca/.

Web Resources

Guide to Crop Protection Saskatchewan:
http://www.publications.gov.sk.ca/details.cfm?p=77706

Plant Breeders Rights:
http://pbrfacts.ca/

Prairie Recommending Committee of Wheat Rye and Triticale:
http://www.pgdc.ca/committees_wrt.html

Variety designation lists. Canadian Grain Commission:
https://www.grainscanada.gc.ca/legislation-legislation/orders-arretes/ocgcm-maccg-eng.htm

Varieties of Grain Crops Alberta:
https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex4069/$FILE/100-32_cwadw2018.pdf

Varieties of Grain Crops Saskatchewan:
http://publications.gov.sk.ca/documents/20/96889-Varieties%20of%20Grain%20Crops_2018.pdf

Varieties registered in Canada. Canadian Food Inspection Agency:
http://www.inspection.gc.ca/plants/variety-registration/eng/1299175847046/1299175906353

4. FIELD SELECTION, OPTIMUM CROP ROTATION, REDUCED TILLAGE

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Introduction

The growing season on the Canadian prairie is short. In a normal year, the growing season starts with last spring killing frost (-2.2°C, 28°F) in mid to late April and ends with the first killing fall frost occurring in mid to late September. The average killing frost-free period was 163.8 ± 12.8d over the period 1961 to 1990 based on 60 weather stations across Western Canada. Therefore, choice of land, crop rotation, and seeding date are very important for many crops to mature including the long-season crop - durum wheat. Overall, studies on the effects of seeding date on durum wheat productivity are limited, but several studies have shown that an earlier seeding increases durum wheat crop yield.

Land selection for durum wheat production

On the Canadian prairies, durum wheat, similar to hard red spring wheat, has been historically grown in summerfallow-cereal-cereal or continuous cereal systems. However, the area of summerfallowing practice has declined significantly in recent years. For example, the proportion of summerfallow area in Saskatchewan decreased from 39% of total arable lands in 2001 to 16% in 2013 (Figure 1). A reduction of summerfallow frequencies in the summerfallow-cereal-cereal rotation systems has been found to increase annualized grain yield with a significant reduction of the durum grain carbon footprint (Gan et al. 2012).

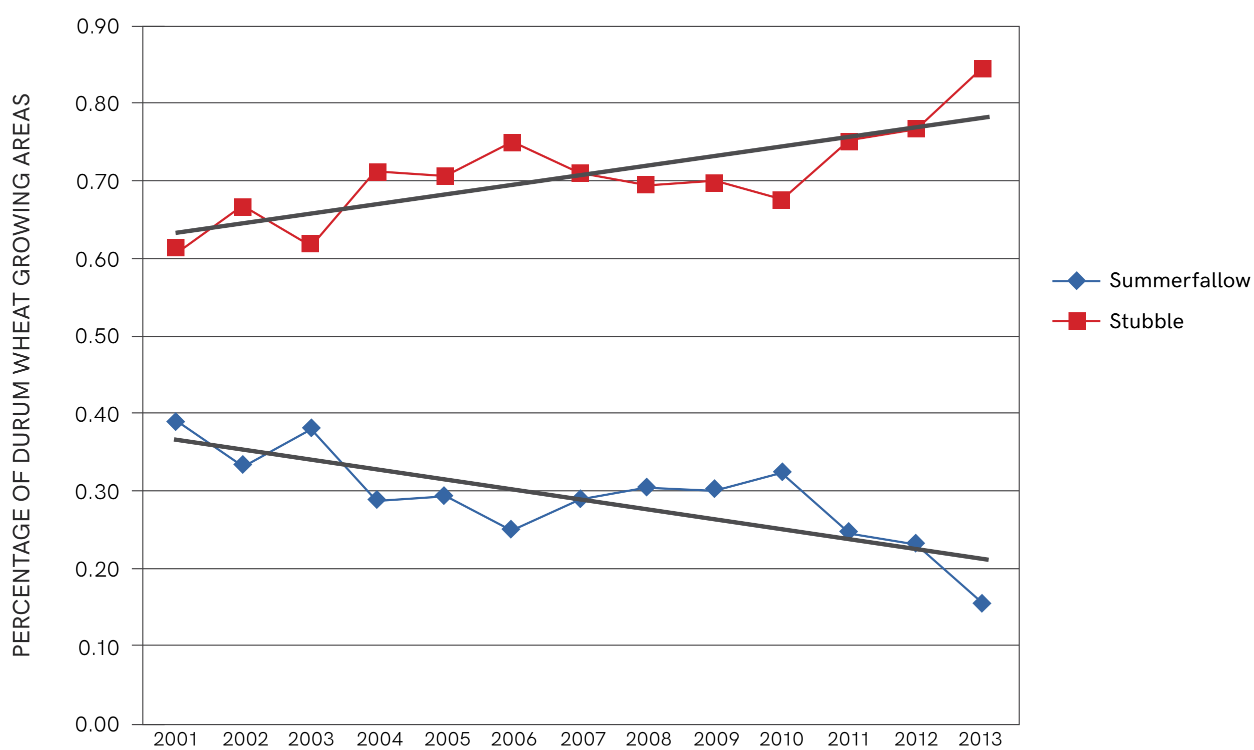

FIGURE 1. The trend in durum wheat growing areas with summer fallow and stubble on the Canadian prairie.

Reduced tillage, stubble height and soil moisture

Producers on the semiarid Canadian prairies (Brown and Dark Brown soil zones) are faced with several major limitations. Two primary ones are soil erosion and lack of water. Both of these limitations can be addressed by adoption of tall standing stubble and reduced tillage practices (Figure 2). Reduction in summerfallow has occurred with adoption of reduced tillage practices, enabled by new equipment, low cost herbicides, varieties with shorter stronger straw, and agronomic practices such as stubble management. (http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-management/flexibility-of-no-till-and-reduced-till-systems-ensures-success-in-the-long-term/?id=1219778199286)

Stubble, left intact and standing, may protect the soil from the wind (Siddoway 1970) and increase snow catchment, and thereby increase soil water reserves through snow melt infiltration Campbell et al. 1992; Steppuhn 1994).

Retention of snow on the field increases with height of standing stubble (Steppuhn 1994) (Figure 3). Compared to uniform 15-cm tall stubble, 30-cm tall stubble typically increases soil water by 5 to 15 mm of water by the spring (Campbell et al. 1992; McConkey et al. 1997). The water conservation benefit of standing stubble over the winter is much greater when compared to fields where residue has been cultivated in the fall (Malhi and O'Sullivan 1990; Lafond et al. 1992).

In summary, snow is an agricultural resource that can be managed to enhance on-farm water supplies, to insulate over-wintering crops from low temperatures, to obtain an extra measure of root-zone water for increasing crop production, and to reduce saline conditions by supplying extra water for leaching (Steppuhn 1994).

Further, standing residue shelters the seedlings in a moister, less-windy microclimate for growth. Cutforth and co-workers (Cutforth et al. 2002; Cutforth et al. 2006; Cutforth et al. 2011; Cutforth and McConkey 1997) found that, exclusive of any snow retention benefit, the grain yield of no-till seeded crops increased by about 3% for every 10 cm of standing residue height.

Tillage flattens any standing residue so its water conservation benefit is lost. Evaporation of soil water increases as tillage decreases the ground cover of residue mulch.Tillage brings moist soil to the surface where its moisture then evaporates, especially from the ridges and uplifted soil clods left by tillage. Tillage makes the surface soil water content more uneven (Manns et al. 2014) and thereby may lower the uniformity of crop establishment under dry conditions.

FIGURE 2. *Wheat crop cut to leave short stubble length (about 10 inches) and long stubble length (more than 20 inches) in the background. Photo Credit: AAFC-Swift Current*

FIGURE 3. *More snow is trapped in tall stubble compared to short stubble. Photo Credit: AAFC-Swift Current*

Obviously, the water conservation benefit of reduced tillage in the spring will be greatest when conditions are driest. In the Brown and Dark Brown soil zones that are particularly prone to periods of dry weather in the spring, low-disturbance direct seeding has greatly improved the reliability of cropping durum on stubble fields. (http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-and-water/adapting-dryland-cropping-systems-for-drought-conditions/?id=1217595502029)

To increase grain yields, producers in the semiarid prairies who direct-seed durum wheat are advised to seed into stubble left standing as tall as practical (at least 12 inches (30 cm)). Durum is often grown in rotation with a pulse crop that has a short stature and crop residue which decomposes rapidly and reduces the snow trapping potential. Canola and mustard have crop residue height and decomposition rate intermediate to durum and pulses. Yield improvements from snow management with cereal stubble usually exceeded the small costs of implementing snow trapping practices (Zentner et al. 1992).

FIGURE 4. *On the Canadian prairie, durum wheat is typically grown in rotations with pulse and oilseed crops to diversify the cropping systems.*
Photo Credit: AAFC-Swift Current

Crop diversification with pulses and oilseeds

Since the mid 1990's, Canadian durum wheat has been produced in more diversified cropping systems where the cereal is rotated with various pulse crops, such as lentil, chickpea and field-pea and with small-seeded oilseed crops, such as canola, mustard and camelina (Figure 4). It is considered that the diversified cropping systems, an alternative to the traditional summer fallow-cereal-cereal system, are one of the major innovations in the Canadian field crop production history.

Many studies have reported that inclusion of pulse or oilseed crops as alternatives to cereal monoculture systems, increases durum wheat productivity. In a three-year cropping system study in southern Saskatchewan with durum wheat as the subsequent crop, following pulse crops (lentil, chickpea and dry pea) and oilseed crop (canola or mustard) and spring wheat as the preceding crops in the previous two years, researchers found that the cropping sequences had significant increases on durum wheat productivity (Gan et al. 2003; Miller et al. 2003a; Miller et al. 2003b). Inclusion of a pulse/or oilseed crop once in the previous two years increased the grain yield of subsequent durum grain by 15% or 5 bus/ac (0.33 t/ha) compared with continuous wheat systems. A similar study for five cycles of cropping sequences on the Orthic Brown Chernozem soil, researchers found that average over five cycles, the wheat-pulse-durum system increased durum yield in Year 3 of the rotation by 60% or 11.5 bus/ac (0.77 t/ha) compared with wheat-cereal-durum system (Gan et al. 2015). Lentil is the most common pulse crop preceding durum wheat in Canada. Lentil has the advantage of higher water use efficiency, but the magnitude of the effect varies with different lentil cultivars (Gan et al. 2017).

The mechanisms responsible for the increased the productivity of durum wheat following annual pulses are not totally clear. However, a body of evidence has shown that it is related to the following three aspects: soil water, soil nutrients and soil microbiome.

Soil water

The inclusion of annual pulses in rotation increases the available water in the soil profile which benefits the cereal crop in the subsequent year. Annual pulse plants have a shallower rooting depth with 77 to 85% of the roots being located in the 0 - 40 cm soil depth with little roots (<6%) beyond the 60 cm depth, while wheat plants root to at least 100 cm depth in lysimeters (Liu et al. 2011a; Liu et al. 2011b). If unimpeded, wheat roots have been shown to achieve about 115 cm length (Hurd 1963). These pulses use 15 to 35% less water during a crop season than cereal or oilseed crops (Wang et al. 2012). Also, pulse crops extract water mostly from the upper 60 cm soil depth and thus crop rotations with pulse crops had the highest soil water contents in the 60-90 cm layer than any other rotation systems (Niu et al. 2017). The unused water - "plant available soil water" below 60 cm is available for the following durum wheat crop. The soil available water at planting is critical for seed germination, stand establishment and early plant growth. However, the period from harvest of Year-2 crops in the fall to the planting of the Year-3 durum wheat the following spring varies from seven to nine months in Western Canada. During this period, soil water is recharged through rainfall and snow melting activity. This may change the soil water profile. Precipitation during a growing season plays a greater role in determining durum yield than soil available water at durum planting in semiarid region of Saskatchewan (De Jong et al. 2008).

Water is key for crop production in the semiarid Canadian prairie (De Jong et al. 2008). The Orthic Brown Chernozem soils usually have some soil water remaining in the 0-1.2 m profile at crop harvest. In the durum wheat growing areas in Western Canada, this amount can be greater than 134 mm, which is the 'permanent wilting point' for the Orthic Brown Chernozem soil (Cutforth et al. 1991). The amount of residual soil water greater than permanent wilting point is considered 'available water', that is available to the crops the following year. Some available water was still remaining in the soil profile after crop harvest, suggesting that the crop was unable to utilize all the water that was available during the growing period or the crop did not require any additional water to complete its cycle.

Soil nutrients

The inclusion of pulses in crop rotation enhanced soil mineral N (NO_3^- plus exchangeable NH_4^+). It is usually the case, that pea and lentil as the previous crops and intensified pea or lentil rotations provide highest total residual soil N content at the 60-90 cm soil depths (Niu et al. 2017). In a rotation study comparing monoculture and diversified cropping systems, it was found that the amount of soil N at planting of durum wheat was consistently higher after lentil treatments (on average 44% higher) than after barley or oilseed flax treatments (Gan et al. 2017). The largest increase in soil N between the preceding crop management practices was in the top 0-0.6 m soil layer with little or no difference below the 0.6 m soil depth.

During the seven to nine-month period from crop harvest the previous fall to the planting of durum wheat the following spring, the soil N status changed probably due to mineralization of soil organic matter and crop straw and root decomposition. These processes resulted in additional N to the soil N pools, even though N leaching may occur in some cases. Studies in southwestern Saskatchewan have shown that the N gained during this period may account for 25% of the total amounts of soil N that were available by planting time of the Year-3 durum wheat (Gan et al. 2017). On the Canadian prairie, a net soil N gained during the postharvest period ultimately contributes to the total amount of N available to the following crop (Kröbel et al. 2012). However, adequate soil moisture is required to stimulate soil microbial activity that is essential for soil N mineralization and accumulation.

Soil microbiomes

The inclusion of annual pulses in rotation stimulates the soil microbial community function that provides feedback to the crops. Some recent studies conducted in the major durum wheat growing areas in Western Canada have shown that pulse plants can modify soil microbial environments. This effect provides positive feedback to soil microbial community and these effects carry over to affect the subsequent cereal crops (Borrell et al. 2016; Yang et al. 2012; Yang et al. 2013), contributing to a strong "rotational effect" (Bainard et al. 2017; Gan et al. 2015). Many abiotic factors influenced soil microbial communities. For example, soil pH and electrical conductivity affect spatial pattern of the microbial community, and phosphate flux and climatic variables affect temporal dynamics of the community (Bainard et al. 2014; Bainard et al. 2017).

Due to improved soil water availability and soil N status, and enhanced soil microbial environments by the inclusion of annual pulses in rotation, the diversified cropping systems have been shown to enhance systems productivity (Gan et al. 2017; Gan et al. 2015) and economics (Khakbazan et al. 2016), increase WUE (Wang et al. 2012) and soil nutrient suppling powers (St. Luce et al. 2015; St. Luce et al. 2016) and enhanced environmental sustainability (Gan et al. 2011). Additionally, the diversified cropping systems with pulses enhanced soil microbial functionality (Esmaeili Taheri et al. 2015; Yang et al. 2013), suppressed pathogenic fungal endophytes (Bazghaleh et al. 2016), and enriched soil biological properties (Bainard et al. 2017; Ellouze et al. 2012).

Green manure organic durum production

Growing organic durum relies on other sources of nutrients critical for durum production. An important strategy is to substitute summerfallow in a rotation with legume green manure crops (Curtin et al. 2000). Black lentil, chickling vetch, and forage pea are some of the candidates for green manure (Mooleki et al. 2016). Green manures grow for a short period of time before being terminated.

Green manure may enhance soil water storage. The preceding green manures increased subsequent durum wheat grain yield by 19% 4.2 bus/ac (0.28 t/ha) compared with dry pea and silage pea and by 54% 10 bus/ac (0.67 t/ha) compared with preceding spring wheat. Overall, these green manures were able to conserve as much rain water as summerfallow (Mooleki et al. 2016). The use of leguminous crops as green manure has additional benefits in that the legume crop adds N to the soil through symbiotic N fixation. This decreases the use of inorganic N fertilizer (Kirkegaard and Ryan 2014) and increases system productivity (Gan et al. 2015). The disadvantage is giving up a sellable crop.

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5. PLANTING DATE AND SEEDING RATE STRATEGIES TO OPTIMIZE GENETICS AND OVERCOME ENVIRONMENTAL CHALLENGES.

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Introduction

Durum wheat producers face a range of challenges associated with growing wheat in the northern latitudes that comprise the Canadian prairies. For agronomists and producers, the key to overcoming these challenges is to harness the synergies from GxExM interactions when the latest genetics (G) are coupled with a holistic wheat management (M) system that is manipulated as needed to suit specific agroecozones (E) (Beres et al. 2017). The optimum for durum production across the prairies is best realized by using a variety that resists stem lodging, has high yield, planting based on soil temperature (2°C to 6°C in the top 2 inches (5cm)), and seeding rates of at least 37 viable seeds per sqft (400 seeds per sqm). This seeding rate will allow producers to consistently achieve a desired plant density range of 20 – 30 plants per sqft (200-300 plants per sqm).

In Western Canada, highly mechanized farming can seed over 2 million acres (almost 1 million hectares) per day. Most farmers can seed a minimum 300 to 500 acres (120-200 hectares) per day and large farmers seed over 1,000 acres (400) hectares per day. The mega farms can seed 2,000 acres (800 hectares) or more per day. New equipment is very efficient: seeders are 80 feet (25 meters) wide with huge seed and fertilizer carts plus anhydrous ammonia (NH_3) or liquid wagons.

A Re-Think on Planting Dates

On the Canadian prairies, durum wheat, similar to hard red spring wheat, has been historically grown in summerfallow-cereal-cereal or continuous cereal systems. However, the area of summerfallowing practice has declined significantly in recent years. For example, the proportion of summerfallow area in Saskatchewan decreased from 39% of total arable lands in 2001 to 16% in 2013 (Figure 1). A reduction of summerfallow frequencies in the summerfallow-cereal-cereal rotation systems has been found to increase annualized grain yield with a significant reduction of the durum grain carbon footprint (Gan et al. 2012).

Historically, the recommended planting date for durum wheat in the Canadian prairies has been early- to mid-May with a targeted deadline of June 10th for many areas. These dates were prescribed largely to meet crop insurance deadlines or a product of on-farm logistics. For example, He et al. (2012) indicated that average commercial spring wheat planting dates were May 9, May 14 and May 15, for Swift Current, Saskatoon and Melfort, SK, respectively. These dates appear late when compared with planting dates they predicted using a DSSAT-CSM model. They pointed out that, to achieve high spring wheat yield, growers must plant as early as possible during suitable weather conditions in the spring when the whole crop was not at sensitive stages when frost might occur. This is largely to ensure the crop has developed sufficient biomass so as to capture maximum radiation by June 21 when photoperiod tends to peak in the Prairies.

Comparing early planting on dryland, early planting under irrigated and late planting over four years, the early planting consistently performed better than late planting within any year, except when moisture was not limiting (Table 1). Early planting, therefore, would be an important integrated crop management strategy (ICM) to optimize genetics and to fully synchronize crop phenology with maximum solar radiation and environmental conditions that achieve high attainable grain yield and quality. Forster et al. (2017) indicated that through a range of environmental conditions in North Dakota, USA, planting durum wheat early was the best option for maximizing yield regardless of cultivar or environment. While early plantings are generally adopted for optimum soil moisture utilization, research in other areas indicates early-plantings can be beneficial in low and high rainfall environments. Durum quality may also be affected as a study conducted in North Dakota indicated that durum wheat semolina extraction, gluten index, and wet gluten values tended to decrease with delayed planting (Forster et al. 2017).

Because durum grown under high moisture conditions takes longer to reach maturity than when grown under less moisture, it is important to plant durum early when grown under irrigated conditions (Table 1). McKenzie et al. (2011) noted in experiments grown under irrigated conditions in southern Alberta that every one-day delay in planting resulted in 1.3 % durum wheat yield decline.

An important consideration for earlier planting is that it can create asynchrony or mismatch between abiotic and biotic stresses. For example, wheat is only susceptible to attack by the orange wheat blossom midge between heading and flowering stages (Midge in Insect section). The adult wheat midge typically emerges in late June or early July, which would synchronize to typical early- to mid-May wheat plantings. However, a strategy of ultra-early planting coupled with resistance genetics may allow the wheat crop to escape infestation (https://www.gov.mb.ca/agriculture/crops/production/print,seeding-early-manitoba.html). The same escape strategy would also apply to the management of Fusarium head blight (FHB) Subedi et al. (2007) observed that later planting dates increased the incidence of FHB. Conversely, early planting results in earlier crop maturity and subsequence harvest dates, which can reduce the risk of early fall frost resulting in durum damage and/or quality downgrading, and may reduce the incidence of FHB infection when combined with appropriate fungicide selection, timing and application techniques.

So, how do we define 'early planting' so a producer can put this knowledge to practice? The Governments of Alberta and Saskatchewan recommend that spring durum wheat can be planted when soil temperature is 4°C to 5°C (Soil Temperatures and Seeding: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/soil-temperatures-and-seeding). If there is sufficient soil moisture, shallower planting e.g. 1.5 inch (4 cm) may be used when the soil temperature is less than 5°C.

TABLE 1. *Description of the twelve environments (E) and the grain yield and relative yield of ten durum wheat genotypes.*

YEAR	GROWTH REGIMES	PLANTING DATE	MEAN AIR TEMPERATURE (°C)	MEAN SOIL[a] TEMPERATURE (°C)	WATER INPUT (mm)	GROWING SEASON MEAN AIR TEMPERATURE (°C)	AVERAGE GRAIN YIELD (t per ha)	AVERAGE GRAIN YIELD (bus/ac)	RELATIVE YIELD [b]
2012	Early-rainfed	May-05	7.4	8.2	222 (+6)[c]	15.9 (+0.3)[d]	2.97	44.3	0.54
2012	Early-irrigation	May-05	7.4	8.2	273 (+57)	16.2 (+0.6)	3.78	56.3	0.68
2012	Late-rainfed	May-30	11.3	11.2	146 (-70)	18.3 (+2.7)	2.4	35.8	0.43
2013	Early-rainfed	May-09	12.6	9.9	194 (-22)	15.8 (+0.2)	4.83	72.0	0.87
2013	Early-irrigation	May-09	12.6	9.9	397 (+181)	16.1 (+0.5)	5.54	82.5	1.00
2013	Late-rainfed	May-29	13.5	13.9	181 (-35)	16.9 (+1.3)	3.98	59.3	0.72
2014	Early-rainfed	Apr-30	7.8	5.1	206 (-10)	14.8 (-0.8)	3.37	50.2	0.61
2014	Early-irrigation	Apr-30	7.8	5.1	359 (+143)	15.2 (-0.4)	3.66	54.5	0.66
2014	Late-rainfed	May-27	15.4	14.7	314 (+98)	15.8 (+0.2)	2.91	43.4	0.53
2016	Early-rainfed	Apr-29	8.1	7.1	376 (+160)	15.7 (+0.1)	4.53	67.5	0.82
2016	Early-irrigation	Apr-30	10.0	8.4	414 (+198)	15.6 (+0.0)	4.04	60.2	0.73
2016	Late-rainfed	May-27	13.8	13.7	291 (+75)	16.0 (+0.4)	3.97	59.2	0.72

[a] Mean soil temperature recorded at 2 inches (5cm) below surface of grass sod at the Swift Current Research and Development weather station.
[b] Relative yield = average grain yield over the 10 genotypes of an environment/the maximum mean grain yield of the genotypes across all 12 environments.
[c] The numbers in parenthesis indicate the deviation from 216 mm, which was mean accumulated precipitation from May to August from 1886 to 2016 in Swift Current, SK, Canada.
[d] The values in parenthesis show the deviation from 15.6 °C, which was mean air temperature from May to August from 1886 to 2016 in Swift Current, SK, Canada.
Source: Lin et al. 2017, SCRDC and PBI, NRC Saskatoon.

Preliminary results of an ultra-early seeding study indicate spring wheat cultivars planted at a high density respond positively to plantings into soils as cold as 2°C in the top 2 inches (5cm). Spring wheat planted later when soil temperature is greater than 6°C, appears to suffer a yield drag compared to earlier plantings. Thus, adhering to 'planting date' instead of using soil temperature as the trigger to begin planting can results in plantings into soil that has warmed well beyond the range that optimizes yield. An updated strategy for durum planting would be a shift away from targeted dates, which are arbitrary and vary from year to year, to using a prescribed soil temperature as the threshold that then targets an ultra-early planting trigger point of 2°C to 6°C in the top 2 inches (5cm). Of course, this is only possible when field conditions permit, which may not occur in every environment in every given year. When early plantings are successfully executed, stability of the system is strengthened considerably with a high sowing density and through the use of a dual fungicide-insecticide seed treatment to mitigate against abiotic and biotic stress.

High Seeding Rates for Optimum Yield and Crop Uniformity

Considerations for the ideal sowing density extend beyond considerations for yield and potential for lodging. Seeding rates can be easily adjusted and yet provide multiple benefits to the crop. Traditionally, seeding rates are manipulated to optimize the ability of the crop to capture available resources and therefore increase yield in rainfed conditions (Isidro-Sánchez et al. 2017), and increased seeding rates ensure high durum wheat yields under irrigated conditions (McKenzie et al. 2011). Moreover, growers may try to compensate late planting by seeding at a higher rate, while traditional seeding rates are often lower at earlier planting dates (Ottman and Tickes 1997). Earlier recommendations for seeding rates in wheat were as low as 7 to 9 plants per sqft (75-100 plants per sqm). These rates produced acceptable yields and were considered optimum in the context of managing water-limiting factors, or, when water was not an issue. However, recent studies indicate these rates don't fully exploit the yield potential, and therefore advocate for seeding rates in the range of 21 to 30 plants per sqft (225 - 325 plants per sqm), irrespective of moisture regime or timing of planting (Beres et al. 2011; Beres et al. 2010b; Isidro-Sánchez et al. 2017; Ye et al. 2017). The new recommendation is to plant at a rate of at least 37 seeds per sqft (400 seeds per sqm) to achieve a desired plant density range of 20 – 30 plants per sqft (200-300 plants per sqm).

Seeding rates have to be adjusted to account for seed germination rate, vigour, emergence mortality, and row spacing. These new and higher seeding rate recommendations were first established for winter wheat (Beres et al. 2010a); 46 seeds per sqft (450 seeds per sqm). More recent studies indicate durum wheat may respond similarly. For example, even in situations where spring wheat was planted into wheat stubble, Beres et al. (2011) observed that the durum cultivar, AC Avonlea (Clarke et al. 1998) displayed significant linear grain yield responses to the highest seeding density of 46 seeds per sqft (450 seeds per sqm) (Figure 1).

LEFT: 150 seeds per 10.7 sq ft (sqm)
RIGHT: 450 seeds per 10.7 sq ft (sqm)

Photo credit: B. Beres, AAFC

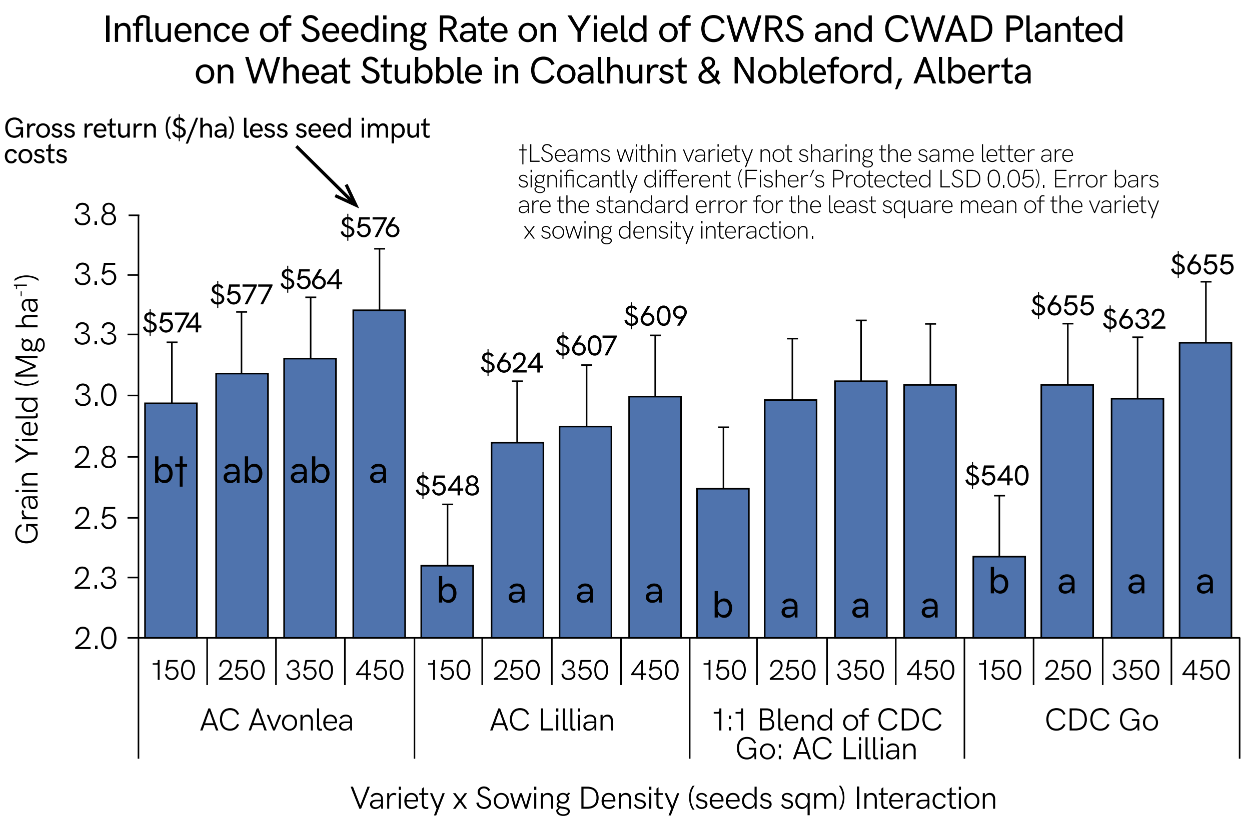

FIGURE 1. *Grain yield responses of Canada Western Amber Durum (CWAD) and Canada Western Red Spring (CWRS) wheat cultivars to varying sowing densities (Beres et al. 2011).*

Two follow up studies also confirmed positive durum responses to higher sowing densities (Isidro-Sánchez et al. 2017; Nilsen et al. 2016). So, what's changed? The responses may relate to the fact that as newer genetics are released with higher yield potential, sowing density may need to increase to exploit the increased yield potential. This was the case when corn hybrids were first released and no changes to yield increase were observed until management practices around seeding rates were altered (Duvick 2005).

Although research has concluded seeding rates as high as 46 seeds sq ft2 (450 seeds per sqm) could be explored, producers may not consistently be rewarded with higher yield nor higher yield returns (Figure 1). However, several other benefits are attained that justify the adoption of high seeding rates at all times. Increased sowing densities increase crop competitiveness and reduce weed competitive ability, both of which lessen the reliance on multiple herbicide applications (Cultural Weed Management).

High seeding rates will also reduce tiller production creating a crop canopy that is compromised largely of main stems, which optimizes uniformity. These changes to canopy architecture will shorten the flowering period and lead to earlier harvest, thus reducing rates of disease infestation from pathogens such as Fusarium head blight, more uniform maturation with fewer grass green kernels from very late tillers, and damage from frost.

Damage from insects such as wheat stem sawfly is also reduced if high seeding rates are adopted. The wheat stem sawfly (WSS) is a stem-boring insect that has been a major pest of wheat in the North American Great Plains for more than 110 years. Damage from WSS can result in up to 30% wheat yield loss, and cost $350 million annually (Beres et al. 2007). Management of WSS is achieved through the use of resistant (i.e. solid-stemmed) wheat cultivars coupled with proper agronomics. With common solid-stemmed wheat, seeding rates must be kept at a moderate level as higher rates will reduce this expression in the culm of the stem (Beres et al. 2011). However, a recent study concluded the newly released solid-stemmed durum cultivars can be planted at high rates as no yield drag or appreciable reductions in stem solidness have been observed (Nilsen et al. 2016). These advancements in durum breeding and new agronomic practices around seeding rates have provided durum producers with a production system that provides stability even in environments with high WSS pressure.

A final consideration for practices associated with seeding rate is ensuring the rate is calculated accurately. Correct calibration of desired seeding rates is based on kernel weight, which can vary greatly between cultivars, wheat classes, seed viability (percent germination), emergence mortality, and environments. It is therefore imperative that producers move away from setting rates based on weight or volume ie. bushels per acre, and to settings that are calculated from the specified kernel weights from the seed lot used. Table 2 illustrates how different kernel weights will influence the volume of seed required for the desired range of 28 to 33 plants per sqft (300-350 plants per sqm). For example, the volume required on a per acre basis differs by almost 0.3 bushel between the cultivars listed when planting at the 23 seeds per sqft (250 seeds per sqm), and differs by 0.4 bushel per acre at the 33 seeds per sqft (350 seeds per sqm) rate. Adoption of higher seeding rates also buffers against variation in seed lot germination; however, if germination falls below 90%, corrections to seed rate calculations are warranted.

There are many online resources for properly calculating and calibrating drills to the correct rate such as the Alberta Agriculture and Forestry wheat seeding rate calculator available at: https://www.agric.gov.ab.ca/app19/loadSeedRateCalc. In summary, planting at a rate of at least 37 seeds per sqft (400 seeds sqm) will allow producers to consistently achieve a desired plant density range of 20 – 30 plants per sqft (200-300 plants per sqm).

The goal of this section was to provide durum growers, retail and consulting agronomists with updated recommendations for timing of planting and sowing density. Careful consideration is required to ensure that the best variety is selected for the environment where the durum is to be grown. Given that every environment presents unique challenges that can vary from year to year, its important the management practices are revisited annually and changed according to anticipated challenges or opportunities the environment will present. Harnessing the synergy of a GxExM interaction for durum production across the prairies is best realized by plantings based on soil temperature (2°C to 6°C in the top 5cm) and seeding rates of at least 37 viable seeds per sqft (400 seeds sqm), using a variety that resists stem lodging, has high yield potential and is rated as least moderately susceptible to Fusarium head blight.

TABLE 2. *Wheat seeding rates calculated based on 1000 kernal weight (kwt)*

SEED RATE PLANTS PER sqft	SEED RATE SEEDS per sqm	CDC FORTITUDE (41.1g)	AC AVONLEA (44.0g)	BRIGADE (48.0g)
19	200	1.2 bu/ac	1.3 bu/ac	1.4 bu/ac
23	250	1.5 bu/ac	1.6 bu/ac	1.8 bu/ac
28	300	1.8 bu/ac	2.0 bu/ac	2.1 bu/ac
33	350	2.1 bu/ac	2.3 bu/ac	2.5 bu/ac
37	400	2.4 bu/ac	2.6 bu/ac	2.8 bu/ac
42	450	2.8 bu/ac	2.9 bu/ac	3.2 bu/ac
46	500	3.1 bu/ac	3.3 bu/ac	3.4 bu/ac

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6. SEED TREATMENTS TO MITIGATE ABIOTIC AND BIOTIC STRESS IN DURUM PRODUCTION SYSTEMS

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Traditionally, consideration for investing in a seed-applied fungicide and/or insecticide treatment was based on anticipated biotic stress caused by seed- or soil-borne pathogens or insects. If risk to a field or farm was considered low the additional input costs for a seed treatment was commonly considered unjustified. Recent research, however, suggests this approach is outdated given the responses to abiotic stress that have been observed in relation to seed treatments. In this section, we will discuss not only the important role seed treatments offer in managing the biotic stressors associated with insects and disease, but also how seed treatments can mitigate abiotic stress.

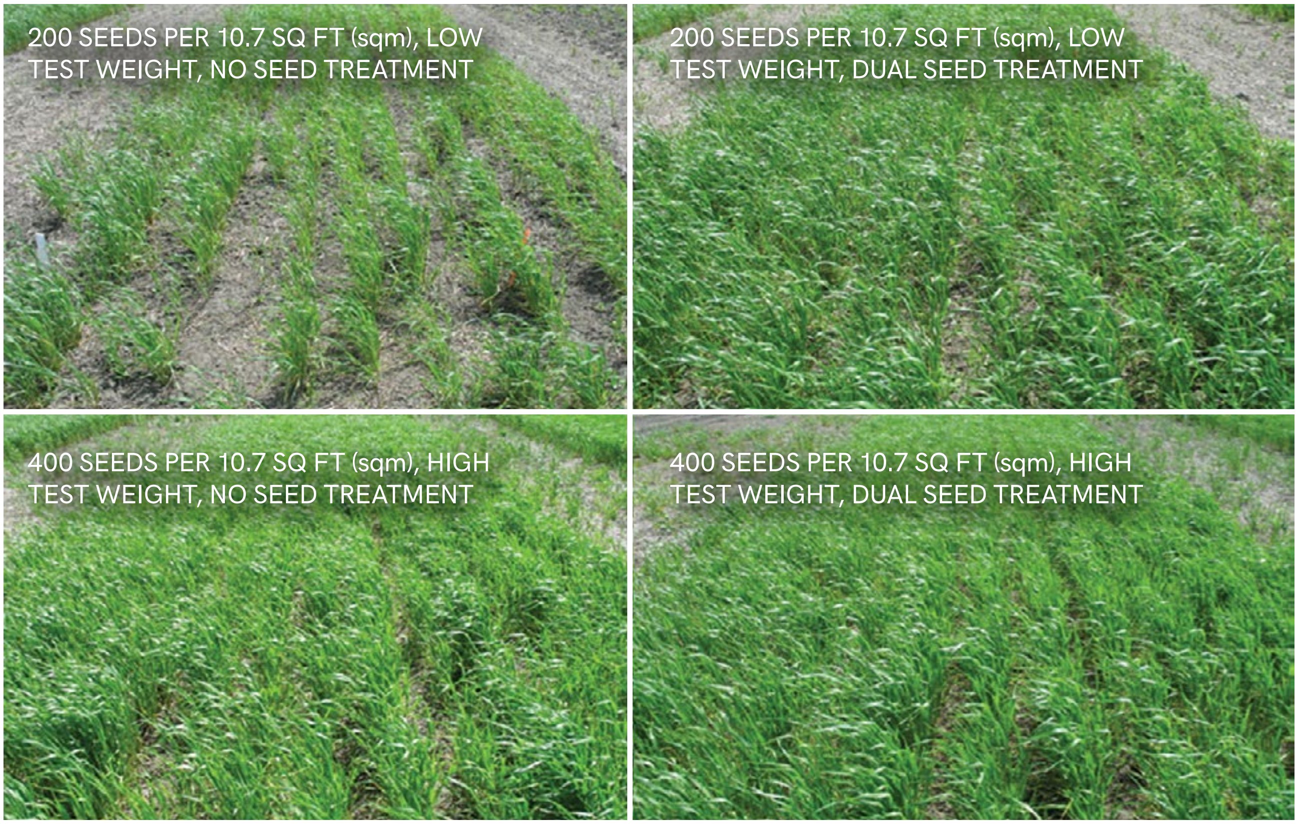
Biotic Stress Management

Seed treatments have proven to be a convenient method to battle early-season insects and diseases (Hopkins 2015). The usual approach was to apply a seed treatment to target either seed-borne or soil-borne plant pathogens (Hewett and Griffiths 1986; Mathre et al. 2001), as seed-applied fungicides may contribute to optimal stand establishment and lessen early-season disease (Menzies and Gilbert 2003; Wiese 1987). McMullen and Stack (2009) indicated that when using diseased seed, appropriate durum seed treatment could result in substantial improvement in germination and seedling vigour. Similarly, Vernon et al (2009) reported improved plant stands can be achieved with imidacloprid, if wireworms are present.

Fusarium head blight (FHB) is a devastating disease of wheat because of its production of mycotoxins (e.g., deoxynivalenol or DON) and direct detrimental effects on grain yield, quality, and marketability. As no wheat cultivar is completely resistant to FHB, greater attention to management strategies is needed, particularly when growers are faced with having to plant their durum crop with seed sourced from a seed lot with greater than 10% Fusarium damaged kernels (Beres 2018). While most attention to FHB control focusses on in-crop fungicide applications as a management strategy of FHB, seed-applied fungicides have been effective in improving stand establishment and yield when there is pressure from FHB caused by *Fusarium graminearum* (Schaafsma and Tamburic-Ilincic 2005). Durum wheat seed treatments using difenconazole, triticonazole, maneb, or fludioxonil significantly improved germination and reduced Fusarium seedling blight in three field trials with 5 - 45 % infected seed. However, no significant improvements in yield were observed in some trials (Jørgensen et al. 2012). In other trials, seed treatments reported increased emergence and yield when levels of seed infection in wheat were high (>50%) (May et al. 2010). While, with low levels of seed infection (≤10%), seed treatments did not improve emergence and grain yield. With moderate levels of infection (25–35%) emergence increased with seed treatment, but grain yield was unaffected.

Abiotic Stress Management

Abiotic pressures may be present in many forms that usually arise from cold ambient and soil temperatures at planting and emergence: snow, excess water, drought, heat stress. Seed treatments were generally not considered as a management tool for abiotic stress until recently. With the introduction of seed-applied neonicotinoid insecticides, researchers established that neonicotinoids such as imidacloprid and clothianidin induce salicylic acid-associated responses, which elicit plant protection to pathogens such as powdery mildew concomitant with abiotic stress tolerance (Ford et al. 2010). A study on eastern Canadian spring wheat reported that a dual fungicide (difenoconazole and metalaxyl) and an insecticide (thiamethoxam) enhanced the freezing tolerance of seedlings.



SEEDING RATE FUNGICIDE INSECTICIDE

Photo credit: B. BERES, AAFC

Beres et al. (2016) noted that seed treatments accelerated emergence in fall and provided high and sustained vigour for winter wheat. Growers that choose to adopt low seeding rates should use a dual fungicide/insecticidal seed treatment to protect against less than desirable crop stand establishment. Turkington et al. (2016) reported that the non seed treated check and the fungicide (metalaxyl) seed treatment produced similarly low grain yield and net returns, whereas the dual fungicide/insecticide seed treatment provided the highest yield and net returns. There is also evidence that fungicide-only seed treatments mitigate against abiotic stress. An eastern Canadian study reported improved wheat plant stands, yield components and grain yield where only a fungicide seed treatment such as tebuconazole was used (Schaafsma and Tamburic-Ilincic 2005). Fungicide treatments with the active ingredient prothioconazole are also purported to improve frost tolerance in wheat by modulating morphological changes to the mesocotyl, and tebuconazole purportedly causes physiological changes that improves root development (Anonymous 2009).

Based on the science-based evidence generated, durum producers are likely to experience positive crop responses when using seed treatments in most environments, and those responses in terms of yield appear to offset the added input costs seed treatments pose. While there remains uncertainty around the regulation of neonicotinoids, the biological evidence overwhelmingly supports their use to mitigate both biotic and abiotic stress. Therefore, growers are encouraged to use a dual fungicide-insecticide seed treatment when possible. An alternative would be a fungicide seed treatment containing multiple active ingredients such as prothioconazole and tebuconazole.

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7. FERTILIZER MANAGEMENT OF DURUM WHEAT

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Introduction

Durum wheat is well suited to production in the southern prairies, particularly in the Brown, Dark Brown and southern areas of the Black soil zones. Durum requires careful attention to nutrient requirements to develop a sound, balanced fertilization program to achieve optimum yields. Four components, known as 4R, provide a framework to achieve cropping goals, increased profitability, enhanced environmental protection and improved sustainability. The 4R's are the right fertilizer source, at the right rate, and the right time, and at the right place. A big 60 bu/ac (4031kg/ha) durum wheat crop requires large amounts of nitrogen, phosphorous and potassium and a smaller amount of sulphur (Table 1).

TABLE 1. *Approximate nutrient uptake of a 60 bu/ac (4031 kg/ha) durum wheat crop at 13% protein. Uptake will vary depending on variety and environmental conditions during the growing season. (Source: R.H. McKenzie)*

DURUM WHEAT	NITROGEN (N)	PHOSPHATE (P_2O_5)	POTASSIUM (K_2O)	SULPHUR (S)
		(lb/ac)		
Total uptake	110-135	40-45	90-120	12-15
Seed only	80-100	30-35	25-28	6-8

Soil Testing

Carefully conducted soil sampling and testing is necessary to determine soil nutrient levels, which can then be used to determine the fertilizer nutrients required and the correct application rates. Detailed information on soil sampling and testing is available on-line at: (Soil Sampling and Testing: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1341)

Nitrogen (N)

Nitrogen is frequently the most limiting nutrient for durum production. Durum responds strongly to the addition of N fertilizer and yield gains in the range of 50 to 70% or more are common.

Research has concluded that N fertilizer application is often the most influential agronomic factor controlling yield and quality. Adequate N promotes vigorous plant growth, a larger leaf area with a darker green color, and reduces non-vitreous kernels or starchy kernel count.

During the growing season, N in older leaves is redistributed to younger leaves to maintain growth. As a result, the older leaves first show the characteristic lighter green to yellow colour followed by withering, which may indicate a N deficiency. The amount of N fertilizer required to achieve optimum yield depends on:

- level of soil nitrate-N (NO_3-N) at the start of the growing season
- N mineralization potential of the soil during the growing season
- available stored soil moisture at the time of seeding
- expected precipitation during the growing season

These conditions can vary greatly from year to year. When a nitrate-N soil test is low, the need for N fertilizer increases, resulting in a greater response to N fertilizer. As stored soil moisture increases or growing season precipitation increases, the need for additional N fertilizer increases. Soil testing for nitrate-N to 24 inches (60 cm) and determining the amount of stored soil moisture before seeding are important in determining optimum fertilizer N rates.

TARGET OF 160 POUNDS NITROGEN PER ACRE

Photo credit: R. McKenzie, AAF

TABLE 2. *General nitrogen fertilizer recommendations for the various soil zones on the prairies. Recommendations are in lb N/ac and vary with spring soil moisture levels (D-dry; M-moist; W-wet) and assumes near normal growing season precipitation. General recommendations are provided for irrigated durum. (Source: R.H. McKenzie)*

	SOIL ZONES												
Soil Test Nitrogen Level (0-24 inches)		Brown			Dark Brown			Black			Dark Gray & Gray		Optimum Irrigation
	D*	M	W	D	M	W	D	M	W	D	M	W	
lb N/ac	..... Recommened N rate in lb N/ac												
0-10	60	80	100	80	100	120	100	120	130	80	100	120	160
11-20	50	70	90	70	90	110	90	110	120	70	90	110	150
21-30	40	60	80	60	80	100	80	100	110	60	80	100	140
31-40	30	50	70	50	70	90	70	90	100	50	70	90	130
41-50	20	40	60	40	60	80	60	80	90	40	60	80	120
51-60	10	30	50	30	50	70	50	70	80	30	50	70	110
61-70	0	20	40	20	40	60	40	60	70	20	40	60	100
71-80	0	10	30	10	30	50	30	50	60	10	30	50	90
81-90	0	0	20	0	20	40	20	40	50	0	20	40	80
91-100	0	0	10	0	10	30	10	30	40	0	10	30	70
101-110	0	0	0	0	0	20	0	20	30	0	0	20	60
111-120	0	0	0	0	0	10	0	10	20	0	0	10	50
121-130	0	0	0	0	0	0	0	0	10	0	0	0	40
130-140	0	0	0	0	0	0	0	0	0	0	0	0	30

**D, M and W – refer to soil moisture conditions at the time of planting. D – dry conditions with 2 inches of stored moisture; M – moist soil conditions with 4 inches of stored moisture; W – wet soil conditions with 6 inches of stored moisture.*

Research conducted in Alberta and Saskatchewan was used to develop general fertilizer recommendations for the various soil zones on the prairies (Table 2). From Table 2, the amount of N fertilizer required by durum for optimum yield can be estimated. However, Table 2 provides general recommendations, and does not take into account crop value and N fertilizer price.

These recommendations assume that about 20, 30, 40, 30 and 50 lb N/ac (22, 34, 45, 34, and 56 kg N/ha) will be mineralized during the growing season in Brown, Dark Brown, Black, Gray and irrigated soils, respectively. Average growing season precipitation (GSP) is assumed for each soil zone. Nitrogen recommendations are provided at three stored soil moisture (SSM) levels of 2, 4, and 6 inches (50, 100, and 150 mm) of water at the time of seeding.

SSM is the amount of plant available water stored in the soil.For example, in the Brown soil zone, if soil test N is between 0 to 10 lb N/ac (0 to 11 kg N/ha), and soil moisture is medium with 4 inches (100 mm) of stored soil moisture, the estimated N mineralization is 20 lb N/ac (22 kg N/ha), and the total amount of N fertilizer recommended is approximately 80 lb N/ac (90 kg N/ha). Nitrogen recommendations for irrigated durum (Table 2) are based on optimum irrigation. Irrigated durum is very responsive to N fertilizer with optimum yields in the range of 110 bu/ac or more (7391 kg/ha). Figure 1 shows the approximate yield response of durum wheat relative to soft wheat, CPS wheat and spring wheat to increasing rates of N fertilizer when soil test N in the 0 to 24 inch depth is 30 lb N/ac (0 to 61 cm depth is 34 kg N/ha), in southern Alberta.

For irrigated durum or in wetter regions of the prairies, it must be noted that durum is prone to lodging. When higher rates of N fertilizer are used, durum is much more prone to lodging. For irrigated durum or in wetter regions, selection of a durum variety with very good lodging resistance is essential. To reduce lodging potential under irrigation, the combination of soil test N, estimated N release from soil and N fertilizer application should not exceed about 180 to 200 lb N/ac (202 to 204 kg N/ha).

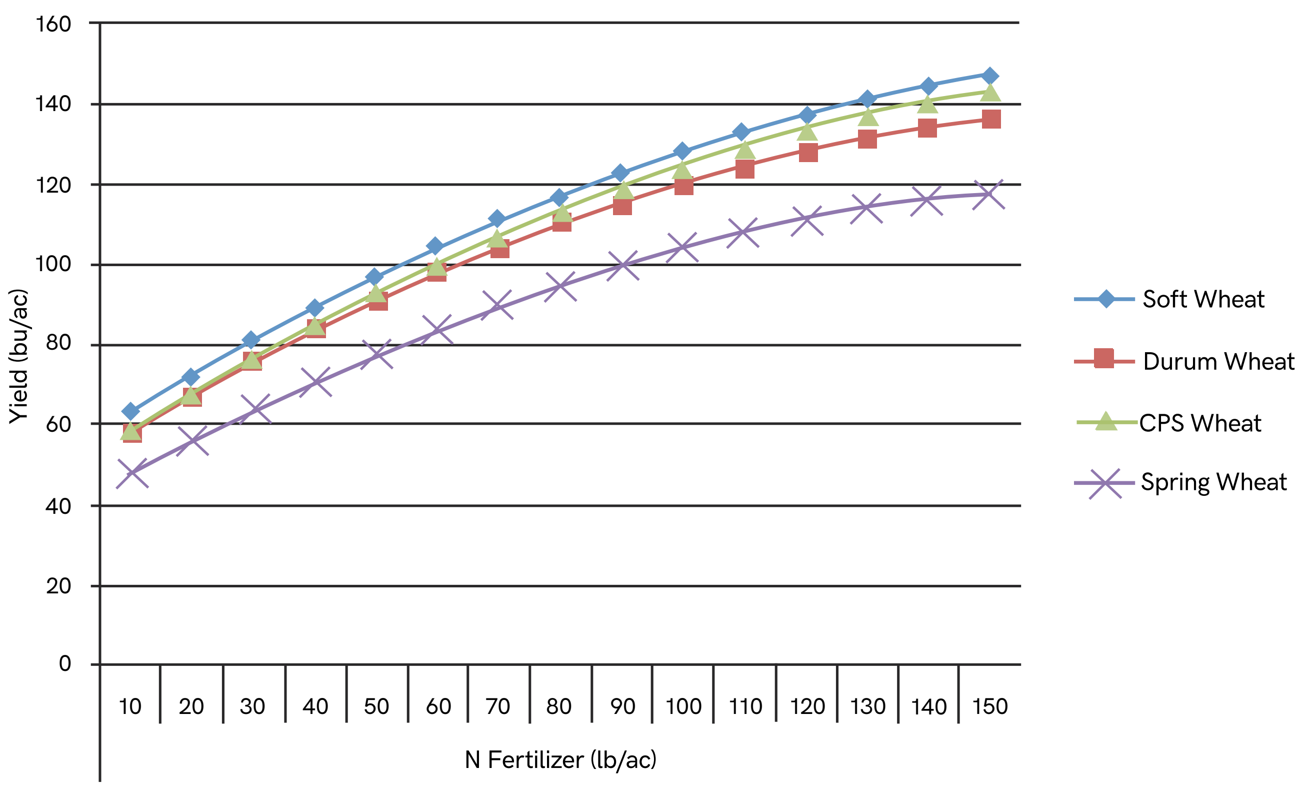

FIGURE 1. *Approximate yield response curve of irrigated soft wheat, durum wheat, CPS wheat and spring wheat in southern Alberta to increasing rates of nitrogen fertilizer when soil test N in the 0 to 24 inch depth is 30 lb N/ac (30 lb N/ac (0 to 61 cm depth is 34 kg N/ha). (Source: McKenzie and Pauly 2013a)*

Ideally, N fertilizer should be side or mid-row banded at the time of planting for best efficiency of uptake in the range of 60 to 70%. Banded N prior to seeding is a good second choice but may delay seeding, and it will disturb and dry out the seedbed, which can affect germination and crop emergence. Broadcast-incorporated N is generally 15 to 20% less efficient than banding and also dries out the seedbed.

In-crop N application of liquid N fertilizer by dribble banding can be used to top dress N at the tillering to stem elongation stage to increase grain protein. However, this practice of N application is usually much less efficient.

TABLE 3. *Safe quantities of seed-placed urea N and Environmentally Smart Nitrogen (ESN) fertilizer for durum, when soil moisture is good (75% of field capacity) (Source: R.H. McKenzie)*

	UREA		ESN	
Seed bed utilization (SBU)	Coarse texture soil	Medium to fine texture	Coarse Texture soil	Medium to fine texture
(%)	lb N/ac		lb N/ac	
5	0	10	0	30
10	15	25	60	75
25	25	35	75	100
33	30	40		

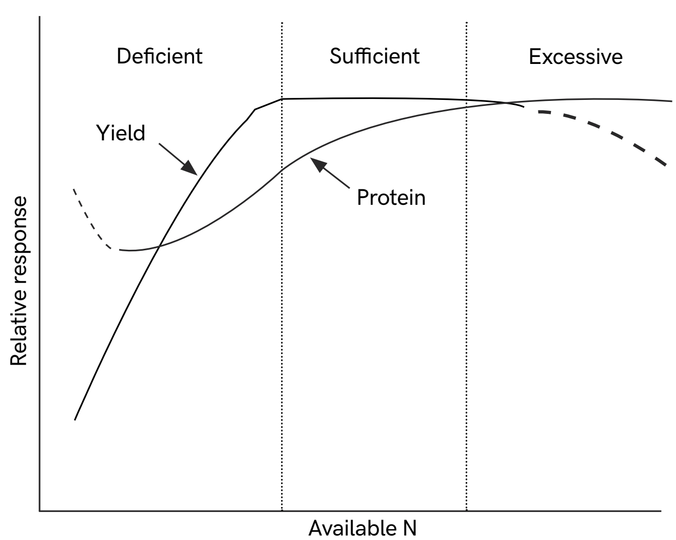

FIGURE 2. *Typical response of grain yield and protein concentration to available nitrogen (McKenzie et al 2006).*

If a rain occurs shortly after in-crop N application to move the fertilizer into the soil, the N efficiency of uptake might be up to 40%. Otherwise, the efficiency is often in the range of 20 to 30%. Usually, it is most effective to apply all N fertilizer at the time of seeding versus applying a portion of N in an in-crop application, unless there are leaching or denitrification concerns four to six weeks after seeding.

Optimizing Nitrogen and Grain Protein

Grain protein concentration is generally unaffected or declines with the first increment of N fertilizer added under very N deficient conditions. But, protein increases rapidly as N availability approaches the amount required for maximum grain yield. Maximum grain protein concentration is generally achieved at levels of N availability higher than that required for maximum grain yield (Figure 2).

Typically, optimum yield of durum wheat is achieved when grain protein is about 13.0 to 13.5%. Depending on moisture conditions, an additional 20 to 40 lb N/ac (22 to 45 kg N/ha), may be needed to increase protein to 15%.

Durum is sensitive to the toxicity effects of urea (46-0-0) fertilizer when placed with or very near the seed. Direct seeded durum should have most of the N fertilizer side banded with at least 1 inch (2.5 cm) of separation between the seed-row and fertilizer band, at the time of seeding.

Table 3 provides information to determine the amount of urea N fertilizer that can be safely seed-placed. Remaining N fertilizer requirements should be side or mid-row banded at the time of seeding or banded prior to planting.

These seed-placed recommendations are based on good soil moisture conditions (soil moisture at 75% of field capacity). If seedbed moisture is poor (soil moisture at <50% of field capacity) N seed-placed rates should be reduced by about 50%.

Table 3 includes recommended safe seed-placed Environmentally Smart Nitrogen (ESN; 44-0-0) fertilizer rates. ESN is a polymer coated slow release urea fertilizer. The coating protects the urea from loss mechanisms and releases N in response to soil temperature and moisture conditions. ESN's polymer membrane allows moisture to diffuse into the granule, creating a urea-N solution.

The solution moves out through the porous membrane into the surrounding soil at a rate that is controlled by soil temperature and moisture to match the N demand of the growing crop. The slow release nature of ESN allows higher rates of N to be seed-placed without injury to germinating seedlings.

The times when ESN provides advantages to durum producers is when higher rates of N fertilizer are seed-placed that could jeopardize seed safety (Table 3) or when environmental conditions are wet and could result in N fertilizer loss due to denitrification or leaching. The slow release nature of ESN also may help to improve grain protein level. Other controlled release fertilizers and enhanced efficiency fertilizers have been studied and products are on the market. (https://www.cdfa.ca.gov/is/ffldrs/pdfs/Ellison_Eric.pdf)

In summary, when direct seeding durum into soil with medium texture and good soil moisture, it is recommended that the rate of N using urea fertilizer, should not exceed 25, 35 or 40 lb N/ac, (11, 33 or 56 kg N/ha) with a seedbed utilization (SBU) of 10, 25 or 33%, respectively, due to the potential toxicity of ammonia to germinating seedlings.

Phosphorus (P)

About 80% of prairie soils are considered phosphorus (P) deficient. Soil P availability to plants can be assessed by soil sampling and testing to determine plant available soil P. Crop response to applied P fertilizer depends on the level of plant available P already in the soil, as well as soil moisture and temperature conditions early in the growing season. The level of plant available P in soil, as measured by a soil test, varies with the extraction solution method used by the laboratory. Some eastern Canadian labs and USA labs use the Bray or Mehlich III soil testing methods for making P fertilizer recommendations. These methods produce different analytical results than the modified Kelowna or Olson methods. The Bray and Mehlich III methods have not been calibrated to western Canadian soils, and therefore should not be used to make P fertilizer recommendations.

Research in Alberta has shown that the modified Kelowna soil test method accurately predicts crop P fertilizer requirements across a wide range of soils common to Alberta. The modified Kelowna method is the accepted method for recommending P fertilizer in Alberta and Saskatchewan.

The Olson method (also referred to as the Sodium Bicarbonate method) is the accepted soil test P method in Manitoba for making P fertilizer recommendations. The Olson method is less effective when soil pH is less than 7.0.

TABLE 4. *Frequency of yield response to seed-placed versus banded phosphate fertilizer in an Alberta wheat study. (Source: McKenzie and Middleton, 2013)*

	WHEAT	
	FALLOW	STUBBLE
Number of sites	7	17
P responsive sites	6	10
Seed-placed P > banded P	4	6
Banded P > seed-placed P	2	3
Seed-placed P= banded P	0	1

It is important to note that P levels in some soils have increased over the years because of repeated annual P fertilization or manure application. As a result, crops grown on these soils are less responsive to fertilizer P application. In recent years, with the high P requirements of canola and pulse crops, that are often included in a crop rotation, many prairie farmers have not been applying enough P fertilizer to replace crop uptake and removal. This has resulted in lower soil test P levels for many farmers. It is important to test soil for plant available P level and apply sufficient P fertilizer to replace amounts removed in harvested crops.When environmental soil conditions are cool and wet, durum tends to be more responsive to P fertilizer versus when soil conditions are warmer or dry. Alberta research suggests that placement of P with the seed is frequently better than banded P, and both methods are superior to broadcast-incorporation of P fertilizer. Durum is frequently most responsive to seed-placed P followed by sided banded or banded phosphate fertilizer. Under most conditions, P fertilizer should be seed-placed for optimum crop response.

Table 4 compares wheat response to seed-placed versus banded phosphate (P_2O_5) fertilizer in southern Alberta on summerfallow and stubble. Seed-placed P

TABLE 5. *Phosphorus fertilizer recommendations at various soil test levels and soil zones using modified Kelowna and Olson soil test P methods. All soil P calibrations are based on a 0 to 6 inch (0-15 cm) depth. Recommendations are given for three soil moisture levels. (Modified from: McKenzie and Middleton, 2013)*

SOIL TEST P (lb/ac) **		SOIL ZONES												
Modified Kelowna Method	Olson (Bicarb) method	Brown			Dark Brown			Black			Gray			Irrigated
		D*	M	W	D	M	W	D	M	W	D	M	W	
		P_2O_5 lb/ac												
0 - 10	0 - 5	30	35	40	35	40	45	40	45	50	40	45	50	70
10 - 20	5 - 10	25	30	35	30	35	40	35	40	45	35	40	45	60
20 - 30	10 - 15	20	25	30	25	30	35	30	35	40	30	35	40	50
30 - 40	15 - 20	15	20	25	20	25	30	25	30	35	25	30	35	45
40 - 50	20 - 25	15	15	20	20	20	25	25	25	30	25	25	30	40
50 - 60	25 - 30	15	15	20	15	15	25	20	20	30	20	20	30	35
60 - 70	30 - 35	15	15	15	15	15	20	15	15	25	15	15	25	30
70 - 80	35 - 40	0	15	15	0	15	15	0	15	20	0	15	20	25
80 - 90	40 - 45	0	0	15	0	0	15	0	0	15	0	0	15	20
>90	>45	0	0	0	0	0	0	0	0	0	0	0	0	0

** Seedbed soil moisture conditions at seeding D = 25%; M = 50%; W = 75% of field capacity.*
***When a soil test for P is reported in parts per million (ppm) for a 0 to 6 inch soil sample depth, multiply the ppm value by 2 to convert to lb P/ac*

is recommended as it is an efficient means of P application, provided the rate applied does not injure the germinating seed or seedlings.

When soil test P levels are medium to high, and significant P fertilizer has been applied in the past 10 to 20 years, an annual maintenance application of phosphate fertilizer can be used to supply crop requirements and replenish soil P that is removed. For greatest efficiency, phosphate fertilizer should be seed-placed with durum. From a seed safety stand point, up to 50 lb P_2O_5/ac (56 kg P_2O_5/ha) can be seed-placed. To obtain best P fertilizer efficiency, adequate rates of N and other nutrients must also be available to the crop, preferable in a side or mid-row band away from the seed.

General phosphate fertilizer recommendations used in Alberta for durum and has been modified to include soil test levels for both the modified Kelowna method and Olson method (Table 5). Soil test P levels in Table 5 are in pounds per acre (lb/ac). When a soil test for P is reported in parts per million (ppm) for a 0 to 6 inch soil sample depth, multiply the ppm value by 2 to convert to lb P/ac.

For more detailed information on phosphorous, refer to (Phosphorus Fertilizer Application in Crop Production, Agdex 542-3, available online at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex920

Potassium (K)

Durum takes up nearly as much potassium (K) as nitrogen and therefore has a high K requirement. Only about 20 per cent of the K taken up by wheat is contained in the seed, while the remaining K in the leaves and stems is normally returned to the soil. The majority of western Canadian prairie soils have extractable soil K levels in the range of 400 to over 800 lb/ac (450 to 900 kg/ha) in the top 0 to 6 inches (0 to 15 cm), which is more than adequate to achieve optimum durum production.

Durum rarely responds to K fertilizer when soil test levels are greater than 250 lb K/ac (280 kg K/ha) in the 0 to 6 inch (0 to 15 cm) depth. On fields that test less than 250 lb K/ac, or on sandy soils or intensively cropped fields, K fertilizer may be required. General potassium fertilizer recommendations for durum are summarized in Table 6.

TABLE 6. *Potassium fertilizer recommendations for durum in the various soil zones of the prairies. All soil K calibrations are based on a 0 to 6 inch (0-15 cm) depth. (Source: Modified from McKenzie and Pauly 2013b)*

		SOIL ZONES				
SOIL TEST K (lb/ac in 0-6 in. depth)		BROWN SOIL	DARK BROWN SOIL	BLACK SOIL	DARK GRAY AND GRAY SOIL	IRRIGATED SOILS
			(lb K_2O/ac)			
0 - 50	Very deficient	80-100	90-110	95-115	95-115	100-120
50 - 100		60-80	65-90	70-95	70-95	80-100
100 - 150		40-60	45-65	50-70	50-70	60-80
150 - 200	Moderately deficient	20-40	25-45	30-50	30-50	40-60
200 - 250		15-20	15-25	15-30	15-30	20-40
250 - 300	marginal	0-15	0-15	0-15	0-15	0-15
>300	adequate	0	0	0	0	0

** Rates above 25 to 30 lb K_2O/ac for wheat should be banded or broadcast to avoid seedling injury.*

Potassium fertilizers are more efficient when seed-placed or banded. However, if phosphate and K fertilizer are both placed with the seed, germination and emergence can be affected.

If K fertilizer is required, rates up to 25 lb K_2O/ac can be placed with the seed but no more than 30 lb P_2O_5/ac should be placed with the seed. If higher amounts of K are needed, the K should be banding or side-banded at seeding to avoid seedling injury.

For more detailed information on potassium, refer to (Potassium Fertilizer Application in Crop Production, Agdex 542-9, available online at:http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex917

Sulphur (S)

Durum has a moderate requirement for sulphate-S (SO_4-S). Durum requires a constant supply of available SO_4-S throughout the growing season, as it is an important constituent of seed protein.

Soils deficient in S could have reduced seed yield without visual symptoms. The general recommendation for durum production is 10 to 20 lb/ac (6 to 11 kg/ha) actual S using a sulphate fertilizer source such as ammonium sulphate (21-0-0-24), when soils are low in S in the 0 to 24 inch depth (0 to 60 cm).

Fertilizers, such as ammonium sulphate, which contain sulphate are most commonly used to correct S deficiencies.

Typically, soils in the Brown and Dark Brown soil zones have adequate SO_4-S in subsoil for durum production. But, if soil test SO_4-S is low (< 10 lb S/ac) in the 0 to 6 inch depth (0 to 15 cm), it may be wise to add 5 to 10 lb SO_4-S/ac (6 to 11 kg SO_4-S/ha). In fields that do test low or medium for SO_4-S, a preventative or maintenance application of sulphate fertilizer at a rate of 5 to10 lb S/ac could be considered to ensure adequate SO_4-S will be available to the crop.

For more detailed information on sulphur, refer to Sulphur Fertilizer Application in Crop Production, Agdex 542-10, available online at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3526

Micronutrients

Micronutrient deficiencies are uncommon with durum on the prairies. However, some regions of the prairies do have low plant available levels of copper (Cu). The diethylenetriaminepentaacetic acid (DTPA) extractant is used to determine plant available Cu. Copper is considered deficient when Cu level is less than 0.2 ppm in the Brown and Dark Brown soil zones and less than 0.5 ppm in the Black and Gray soil zones. Broadcast and incorporated rates of 3 to 10 lb/ac of

Cu in the form of copper sulphate or copper oxide is recommended for deficient soils. Soil application rates should be effective for five years and possibly up to 10 years. Foliar application is not as consistent but can be used after deficiency symptoms are observed. Foliar applications are required annually and are most effective at the late tillering growth stage. If the deficiency is severe, two applications (mid-tillering and boot stage) are necessary. Foliar rates of between 0.2 to 0.3 lb/ac are recommended. For more detailed information on micronutrients, refer to (Micronutrient Requirements of Crops, Agdex 531-1 available online at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex713

Fertilizer Injury with Durum Wheat

Fertilizer injury can occur by two main mechanisms: ammonia toxicity and salt injury. Ammonia (NH_3) toxicity occurs when urea $[(NH_2)_2CO]$ is placed with or very near seed. During the urea breakdown process, ammonia is released near germinating seedlings. Higher concentrations of NH_3 near germinating seed can be toxic. When soil moisture conditions are good, hydrogen (H^+) ions from water (H_2O) will rapidly attach to ammonia to convert to ammonium (NH_4^+), which minimizes potential ammonia injury. The ammonium is then gradually converted to nitrate-N (NO_3^-) by soil bacteria for plant uptake.

AMMONIA TOXICITY IS GREATER WHEN:

- Higher rates of urea are seed-placed causing higher NH_3 concentration levels
- NH_3 persists longer in soil which usually occurs when soil moisture is poor
- NH_3 persists longer in soil when soil pH conditions are higher (>7.5)

In soil, ammonia will establish an equilibrium with ammonium that is dependent on soil pH, with soil pH >7.5 favoring the ammonia form, and the concentrations of each form of nitrogen present. Processes that reduce ammonium concentration in soil, such as dilution by increased soil moisture or the adsorption of ammonium ions to clay and/or organic matter (cation exchange complex) will reduce the toxic effects of ammonia. The conversion of ammonium to nitrate also reduces ammonia toxicity, but this process is usually too slow to reduce the effects of seed-placed N fertilizer with germinating seed.

Salt injury occurs when higher rates of fertilizers are placed near germinating seeds. The salts in the fertilizer cause injury or death of a seedling. Injury occurs when the concentration of fertilizer salt in the seed row is greater than the concentration of natural salts within the cells of the germinating seed, resulting in higher osmotic pressure in the soil versus the seedling. This causes water to move out of the seedling cells. When water moves out of plant cells, the tissue desiccates, causing injury or death of the seedling. The term fertilizer burn comes from the visual appearance of blackened seed and roots.

Soil environmental conditions, particularly seedbed soil moisture, will vary each spring. As a result, fertilizer injury may occur in one year but not another year, in the same field with the same crop and seed-placed fertilizer, due to soil moisture and temperature differences during seed germination and emergence. Under conditions with good soil moisture, dissolved fertilizer salts are less concentrated in the soil and will diffuse away from the fertilizer band and become diluted in the soil solution. When soil moisture conditions are very good to excellent, this will greatly reduce the osmotic pressure and little or no fertilizer salt injury will occur to germinating seedlings. When seedbed soil moisture conditions are marginal or very poor, fertilizer salts become more concentrated in the soil solution resulting in a higher osmotic pressure causing a greater potential injury to germinating seedlings. Fertilizer injury is an increasing concern in drier spring soil moisture conditions immediately after seeding. Also, when soil temperature is cooler, roots grow more slowly, causing roots to be exposed to the higher concentration of fertilizer for a longer period of time.

Salt index (SI) of a fertilizer is a measure of the salt concentration that fertilizer induces in the soil solution. Salt index is the ratio of the increase in osmotic pressure produced by a fertilizer material. Nitrogen (N), potassium (K) and sulphate-sulphur (SO_4-S) fertilizers generally have higher SI values than phosphorus (P) fertilizer (see examples in Table 8). Salt index can be used to compare fertilizer materials but cannot be used to determine the amount of fertilizer that will cause injury.

TABLE 8. *Salt index of some common fertilizers. The higher the salt index, the greater the potential salt injury.*

FERTILIZER TYPE	ANALYSIS	RELATIVE SALT INDEX PER UNIT OF NUTRIENT*
Urea	46-0-0	1.62
Urea-ammonium nitrate (UAN)	28-0-0	2.23
Ammonium sulphate	21-0-0-24	3.25
Ammonium thiosulphate	12-0-0-26	7.53
Mono ammonium phosphate	11-52-0	0.41
Potassium chloride	0-0-60	1.94

** Salt index per unit of nutrient equals 20 lbs.*

Further, seedbed soil moisture conditions and soil characteristics are often variable in fields due to variable topography and variable soil texture conditions. When soil environmental conditions are less favorable, the negative effects of seed-placed fertilizer are greater in drier, upper slope position soils and knolls versus lower slope areas, which often have better soil moisture conditions and higher soil organic matter level.

Table 3 provides safe rates of seed-placed urea N and ESN fertilizer for durum, when soil moisture is good (75% of field capacity). For these N rates, up to 50 lb P_2O_5/ac can also be safely seed-placed with durum, but assumes no K or S will be seed-placed.

Very careful consideration is needed when considering seed-placing other fertilizers such as potassium chloride or sulphate sulphur. Most farmers place phosphate with the seed and even some N fertilizer. Great care is needed when considering the combined effect of seed-placed P coupled with K and/or S fertilizer. Remember, both 0-0-60 (potassium chloride) and 21-0-0-24 (ammonium sulphate) have a relatively high salt index per unit of nutrient (Table 8). If K or SO_4-S are seed-placed, N or P_2O_5 seed-placed rates must be appropriately reduced to avoid injury to germinating seedlings.

For greatest seed safety with durum wheat, a wise strategy is to seed-place P fertilizer and place all remaining fertilizer in a side-band away from the seed at the time of planting.

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8. IRRIGATION MANAGEMENT OF DURUM WHEAT

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Introduction

Durum wheat can be very productive under irrigation. Selection of a durum variety that has strong straw and very good resistance to lodging, has at least a moderately susceptible rating to FHB is of key importance (Variety Selection Table 1). Successful durum breeding has resulted in new durum varieties that are rated "Very Good" for lodging resistance. As well, new semi dwarf durum varieties are being developed, that will be well suited for irrigation. Development of a good nutrient management plan for irrigated durum is also important to achieve optimum grain yield and high protein content. (Fertility management Section 7)

The costly mistake most farmers make when irrigating durum wheat is not applying enough water to keep up with crop water requirements. Good irrigation water management is simply determining the correct amount of irrigation water to apply, at the right times to achieve optimum yield. The goal is to ensure the crop is never under water-induced stress that would limit yield potential.

IMPORTANT THINGS TO INCLUDE:

a) The soil texture of each field to estimate the water holding capacity and amount of plant available water of each soil type in each field

b) The allowable depletion of soil moisture that can be removed from each soil type before irrigation is required. Allowable depletion varies with different crops

c) Know how to check soil moisture content of each field and frequently throughout the season

d) Know the daily water use of durum wheat at each growth stage

e) Know the effective rooting depth

f) Know the irrigation system gross and net water output to apply correct amounts of irrigation water

Soil Texture

The amount of water a soil can retain depends on the texture of the soil. Soil texture refers to the proportion of different sized mineral particles in soil.

The soil particles sizes are:

SAND -	2.0 to 0.05 mm in size
SILT -	0.05 to 0.002 mm in size
CLAY -	<0.002 mm in size

Sand particles are the largest, silt is medium sized and clay particles are the smallest. The relative proportions of sand, silt, and clay particles affect the pore sizes in soil, which affect the ability to hold and retain water. The proportions of sand, silt and clay determine classes of soil texture (Figure 1). Soils with higher amounts of clay have a greater abundance of small pores and can retain more water than sandy soils that have larger sized pores. In sandy soils with larger pores, water is pulled downward and freely drained from soil by gravity.

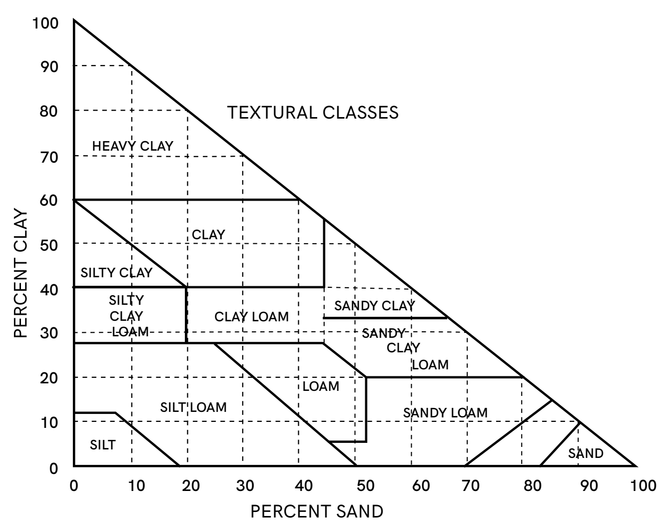

FIGURE 1. *Soil texture classes, based on percentages of clay and sand. The remainder of each class is silt. (Source: Soil Classification Working Group, 1998)*

Texture can be determined in the laboratory using mechanical analysis or can be estimated by wetting soil and kneading it between the thumb and forefinger using the Hand-Feel method. Typically, soil texture can be divided into three main groups: coarse, medium and fine. Fine textured soils are: Clay, Silty Clay, Clay Loam and Sandy Clay. Medium textured soils are: Silty Loam, Sandy Clay Loam, and Loam. Coarse textured soils are: Sandy Loam, Loamy Sand and Sand. A Loam textured soil is typically made up of about 40% sand, 40% silt and 20% clay.

The approximate amount of plant available water varies by soil texture (Table 1). The values in Table 1 are for soil textural classes in Alberta, which are applicable to the prairie provinces.

Understanding Soil Water

A soil is at saturation point (SP) when all soil pores are filled with water after prolonged soaking rain. Normally, within a day or two, gravity will pull away free water out of the soil profile and the remaining soil water content is then referred to as field capacity (FC).

Permanent Wilting Point (PWP) occurs when plants have extracted water to the level that cause plants to wilt and die. The "Bucket Model" of soil water, illustrates saturation point, field capacity and permanent wilting point for a clay soil (Figure 2). The soil water that is between field capacity and permanent wilting point is called plant available water (PAW), which is the amount of water that plants can utilize. There is still a fair amount of water remaining in soil below permanent wilting point but the water is completely unavailable to plants. For example, a clay soil, in a 100 cm root zone, there would be 160 mm of unavailable water in the soil.

About 40% of the plant available water in soil can be extracted by wheat without incurring any water-limiting stress that would affect crop yield or quality. After about 40 to 50% of the available water is used, it gradually becomes increasingly difficult for durum wheat to extract water.

For irrigation farmers, a critical term to understand is allowable depletion (AD), which is the amount (percent or depth) of water that can be removed from soil without significantly affecting crop yield or inducing crop water stress and affecting crop yield or quality.

This water is referred to as the readily available water (RAW). The AD for durum wheat is about 40% but is less for more sensitive crops such as potato and bean.

The total amount of water available to a crop depends on the water-holding capacity of a soil (Table 1) and the effective root zone depth of a crop. The AD will vary with soil type, crop type, stage of crop growth and effective rooting depth of the crop. Allowable depletion is usually determined and expressed in mm per depth of soil.

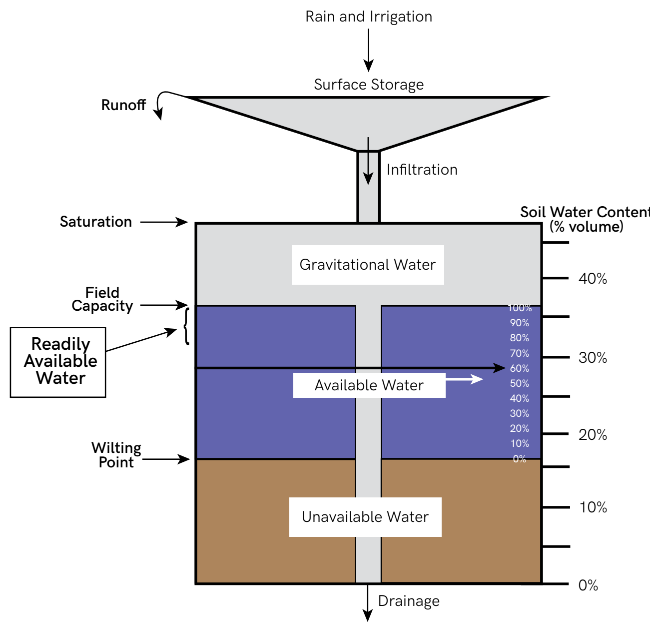

FIGURE 2. *"Bucket Model" of soil water levels showing saturation point, field capacity and permanent wilting point, and the soil water forms including gravitational water, plant available water, readily available water and unavailable water for a clay soil. (Figure credit: Dr. S. A. Woods, Alberta Agriculture and Forestry)*

Effective Crop Rooting Depth

The effective rooting depth of a durum wheat crop is where most of the plant roots are concentrated and extract water for uptake. For durum wheat, rooting depth gradually increases during the vegetative growth period, and at reproductive growth at early grain filling, root development ceases. The effective rooting zone (ERZ) is the soil depth where durum wheat roots take up most of their water. For a typical mature crop of irrigated durum wheat, the ERZ is approximately 100 cm deep.

TABLE 1. *Approximate available water at field capacity of various soil textures (Alberta Agriculture, 2004).*

SOIL TEXTURE	APPROXIMATE AVAILABLE WATER AT FIELD CAPACITY (mm water/ 100 cm of soil)	(mm water/ 25 cm of soil)
Loamy sand	100	25
Sandy loam	140	35
Loam	180	45
Sandy clay loam	160	40
Silt loam	200	50
Clay loam	200	50
Silty clay loam	220	55
Sandy clay	170	43
Silty clay	210	53
Clay	190	48

Roots can extend down to 115 cm, but the majority of the roots are within the top 100 cm. Typically, roots are more concentrated in the upper half of the root zone. As a result, durum wheat usually extracts the majority of water from the upper half of the effective root zone (top 50 cm), where there is a greater abundance of roots and water is easily accessed. Also, in the upper half of the root zone, soil temperature is warmer, soil organic matter levels are higher, soil biological activity is greater, plant available nutrient levels are higher and soil aeration is more favorable, all of which provide desirable conditions for more abundant durum wheat root development.

Typically, about 40% of water is taken up from the upper 25 cm of the root zone and about 30% of water comes from the 25 to 50 cm of the root zone for a total of 70% of durum wheat water requirements. In the 50 to 75 cm depth about 20% of the durum wheat water requirement is taken up and in the 75 to 100 cm depth only about 10%, for a total of 30% of durum wheat water requirements supplied by the lower half of the ERZ.

With about 70% of durum water requirement taken up from the upper half of the ERZ, a very good irrigation management practice for irrigation farmers is to ensure soil water is maintained in the upper half to the ERZ throughout the growing season to prevent crop water stress. An effective irrigation management strategy is to build up soil moisture to near field capacity in the full 100 cm root zone in the spring. And thereafter maintain soil moisture in the top 50 cm between field capacity and 60% of available water throughout the growing season.

Crop Water Use and Evapotranspiration

Crop water use is referred to as "evapotranspiration" or "ET." Evapotranspiration is the combination of water evaporation (E) from soil, and water used by plants for growth and transpiration (T). Transpiration refers to the water released to the atmosphere through the stomata, which are small pores mostly on the underside of durum wheat leaves, as the plants release water vapor to avoid heat stress.

The approximate water use for durum wheat varies by growth stages over the growing season (Figure 3). Note this crop water use curve was developed from research in southern Alberta. Crop water use will vary slightly in different regions due to varying crop, soil and climatic conditions. The graph shows a smooth curve, which is based on long-term averages, whereas actual measurements on any given field will fluctuate day-to-day with changes in weather. Water use can be quite variable depending on environmental conditions such as temperature, humidity, solar radiation, day length, soil moisture level and wind. Daily water use by durum can be over 10 mm per day when weather is very hot and windy.

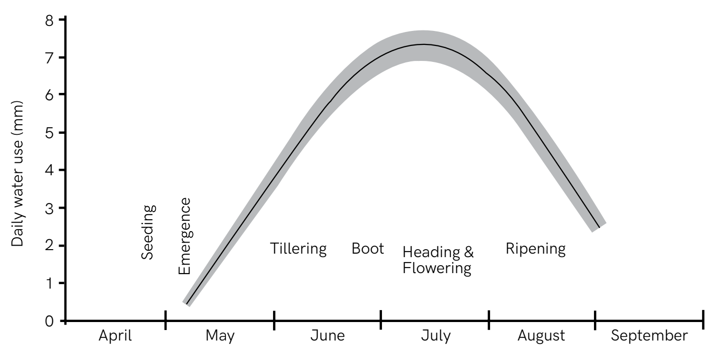

FIGURE 3. *Approximate daily water use for durum wheat, when soil moisture is adequate throughout the growing season. Daily water use can vary considerably due to crop cultivar, plant density and environmental conditions. (Source: Alberta Agriculture and Forestry, 2011. Adgex 112/561-2)*

For irrigation farmers in southern Alberta, daily crop water use can be accessed at the Alberta Agriculture web site: http://agriculture.alberta.ca/acis/imcin/irri-cast.jsp A farmer can select the weather station nearest their farm, then enter their crop information to find out estimates for the daily water use for their crops.

Pivot Irrigation Efficiency

Pivot irrigation is by far the most common method of irrigating durum wheat in Western Canada. Low pressure pivots with drop tubes and spray nozzles have become the most common form of pivot irrigation due to ease of operation, water application efficiency and energy efficiency.

To accurately manage pivot irrigation, it is important to know to how much water your pivot is actually applying! A common length of pivot is about 1310 ft (400 m), with an end volume gun covering another 50 ft, to irrigate about 133 ac of 160 ac quarter section. These are commonly referred to as quarter section pivots.

It is important to recognize that pivots are not 100% efficient in applying water. Gross irrigation water application is the amount of water put out by the irrigation system. The net irrigation water application is the amount of water that is actually stored in the soil after irrigation. The net divided by the gross irrigation water application is called the irrigation application efficiency. Generally, a low-pressure pivot with drop tubes applies water at 80 to 85% efficiency and a high-pressure pivot with impact nozzles is about 75% efficient, but these percentages can vary significantly. The level of water application efficiency varies with wind speed, air temperature and other factors such as pivot operating speed.

When an irrigation system applies water, a portion of the water applied is lost through evaporation of spray water before reaching the soil, water evaporation from the soil surface and crop canopy, and by surface runoff when the water application rate exceeds the infiltration rate of the soil. Efficiency is also affected depending on time of day when water is applied. Water application efficiency in hot windy weather at mid-day is much lower than application efficiency when air is calm and cool during night time conditions.

Table 2 shows the gross water application in mm for a 133 ac pivot with an output ranging from 700 to 1200 US gallons per minute (gal/min), when completing a full circle in 24, 48, 72 and 96 hours (1, 2, 3 and 4 days). Table 3 shows the net water application in mm, for a pivot with the same conditions, assuming a water application efficiency of 85%. Note that using 85% efficiency is a simplistic approach as evaporation losses vary with pivot speed and time of day of application. Other factors, in addition to the weather factors, may include condition of the nozzles and pump, and overall repair of the pivot. (Information in Tables 2 and 3 are provided in US gallons per minute, as all pivot irrigation equipment used in Canada comes from the USA, therefore pivot, nozzle and pump specifications are provided to farmers in US gal/min.)

Important information for pivot irrigation managers is to have a good understanding of gross and net water output of each pivot irrigation system on the farm. If net water application is over-estimated, it will cause under application of irrigation water which could lead to reduced crop growth and yield.

TABLE 2. *Approximate gross water application in mm with a 133 acre pivot with an output ranging from 700 to 1200 US gallons/minute and taking 24 to 96 hours to make a complete circle. (Source: R. H. McKenzie)*

HOURS TO COMPLETE CIRCLE	US GALLONS / MINUTE 700	800	900	1000	1100	1200
	GROSS WATER APPLICATION IN MM					
24	7.1	8.1	9.1	10.1	11.1	12.1
48	14.2	16.2	18.2	20.2	22.2	24.2
72	21.3	24.3	27.3	30.3	33.3	36.3
96	28.4	32.4	36.4	40.4	44.4	48.4

TABLE 3. *Approximate net water application in mm with a 133 acre pivot with an output ranging from 700 to 1200 US gallons/minute and taking 24 to 96 hours to make a complete circle, assuming an 85% water application efficiency. (Source: R. H. McKenzie)*

HOURS TO COMPLETE CIRCLE	US GALLONS / MINUTE 700	800	900	1000	1100	1200
	NET WATER APPLICATION IN MM AT 85% EFFICIENCY					
24	6.0	6.9	7.7	8.6	9.4	10.3
48	12.1	13.8	15.5	17.2	18.9	20.6
72	18.1	20.7	23.2	25.8	28.3	30.9
96	24.1	27.5	30.9	34.3	37.7	41.3

Pivot Irrigation Management

Initially, at the start of the growing season, an irrigation manager must ensure adequate water is available for durum wheat seed germination to ensure excellent emergence and stand establishment, and early crop growth, by application of light, frequent water application. This is possible with pivot irrigation systems, that apply rates as low as 4 to 7 mm with a quarter section pivot (about 133 ac) in a 24 hr period. The advantage of pivot irrigation is the flexibility of applying irrigation water in varying amounts on crop water requirements. Water can be applied during early crop stages to promote vigorous growth and at the same time, apply additional water to increase available soil water reserves in the entire plant root zone to provide a reserve of water during peak crop water use later in the growing season.

Most farmers typically have quarter section pivots that put out about 800 to 900 US gal/min. If a 900 US gal/min pivot makes a full circle in 24 hr, the gross water applied is 9.1 mm and the net application is 7.7 mm, assuming 85% efficiency (From Tables 2 and 3). Durum wheat has an average peak water use in the range of 7 to 8 mm/day of water. But, peak water use for durum wheat at the heading growth stage can be over 10 mm/day of water, when daily temperatures are over 30°C and weather is windy.

In mid-summer, when prolonged hot weather occurs, a 900 gal/min machine may not be able to keep up with daily crop water use. If a pivot system cannot keep up with peak water use requirements, growth and yield may suffer.

It is important to note that assuming that low pressure pivots are always 80 to 85% efficient is simplistic. The operating speed can make a huge difference in efficiency (Table 4). The percentage of water loss due to evaporation from the spray, and evaporation from the soil and crop canopy is increased, as the time to make a circle is decreased. For example, in Table 3, a 133 ac quarter section centre pivot with a gross water application of 900 US gal/min with an assumed water loss of 4 mm per application results in an application efficiency of 56% when the pivot speed to make a full circle is one day. If the pivot speed is reduced to making a full circle in two and three days the efficiency is improved to 76 and 85%, respectively. It is important to run pivots more slowly to reduce evaporation losses and for best water application efficiency, but quickly enough to minimize runoff losses. One caution is that irrigators must remember that, if it takes three days to make a full circle, the last part of the field irrigated will be much drier than the parts of the field where irrigation was started. This must be considered when planning for irrigations.

TABLE 4. *A 133 acre quarter section centre pivot with a gross water application of 900 US gal/min with assumed water losses of 4 mm per application, results in reduced application efficiency when the pivot speed is increased and efficiency is increased when pivot speed is reduced to make a full circle. (Source: R. H. McKenzie)*

TIME TO MAKE A FULL CIRCLE (HOURS)	GROSS WATER APPLICATION (MM)	EXPECTED WATER LOSSES FOR ONE CIRCLE (MM)	NET WATER APPLICATION (MM)	WATER APPLICATION EFFICIENCY (%)
24	9.1	4	5.1	56%
48	18.2	4	14.2	78%
72	27.3	4	23.3	85%

To effectively manage pivot irrigation systems, it is critically important to develop a good understanding of the net water application for each pivot system on the farm, monitor your soil water content frequently, and do your best to match water application with daily crop water use for best irrigation management.

Measuring Soil Moisture

The ability to rapidly and accurately measure soil moisture is critical for irrigation and dryland farmers. Knowing the soil moisture level relative to field capacity and permanent wilting point is necessary to determine the amount of water in soil. There are a number of different tools that can be used to measure soil moisture. For most farmers, the simplest and easiest way is using the Hand-Feel method. This procedure uses a Dutch soil auger or soil probe to take soil samples from specific depths in the plant root zone and feel the soil to estimate the soil water content. Different soil textures have a unique feel with specific characteristics relative to the soil water content. With experience, a farmer can reasonably estimate a soil's moisture content. The USDA has excellent information on using the Hand-Feel method to estimate soil moisture, available on-line at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf

Various types of soil moisture sensors are available that can be installed in soil to measure moisture content. Reliability is an issue with some sensors and they can be costly to purchase. However, in the future it will be possible to have soil moisture sensors installed in the field to provide moisture content on a real-time basis. Sensors can be electronically linked to advise a grower of soil moisture conditions without having to be in the field.

There are also evapotranspiration (ET) based irrigation management methods to assist with determining when to irrigate. These are sometimes referred to as weather-based methods. The general approach to these methods is to maintain a running balance of current soil moisture available to the plant by tracking the ET losses and the additions from irrigation and precipitation. This is similar to maintaining the balance in a bank checking account and is referred to as the "checkbook" method of irrigation scheduling.

Alberta has a weather station network referred to as the Irrigation Management Climate Information Network (IMCIN) that collects data used for ET-based irrigation management (AAF 2016). In Alberta, crop water requirements are increasingly being estimated by a web-based calculator available at the IMCIN website and by the Alberta Irrigation Management Model (AIMM). The Alberta IMCIN is an irrigation scheduling decision-support system that uses data from the nearest meteorological station to assist in on-farm irrigation scheduling operations. The IMCIN calculator, known as IRRI-Cast, and the AIMM use the modified Penman Monteith equation to estimate ET (AAF 2016). This ET function assumes ideal crop and growing conditions. If ideal conditions do not exist, over-estimation of crop water use may result.

The AIMM software is unique in that it is capable of forecasting crop water requirements and tracking available soil water throughout the growing season in the major irrigated areas of southern Alberta (AAF 2016). The AIMM is a detailed software program that is specific to individual fields. A unique feature of the AIMM program is that it has been combined with center pivot communication and control technologies to enable an irrigator to effectively manage irrigation on a large number of fields to save time, energy, and labor. The AIMM program also has the capability of keeping records on irrigation water applied, pump specifications and operations, weather data, and other field records. The AIMM program is adaptable and can be applied to various geographic locations including Saskatchewan and Manitoba, but it has features specific to irrigation in southern Alberta.

TESTING FOR MOISTURE AVAILABILITY

Photo credit: R. McKenzie, AAF

Pivot Management Example

The effective rooting depth used for durum is 100 cm under favourable soil conditions. Table 5 shows an example of a soil profile to 100 cm with loam textured soil in the surface 50 cm and clay loam soil in the 50 to 100 cm depth. Table 5 shows the amount of total soil moisture (from Table 1) to 100 cm and the readily available moisture, assuming the safe depletion is 40% of the total moisture for each depth. In this example, the total readily available water in 100 cm is 86 mm. However, about 70% of crop water requirements is taken up from the top 50 cm root zone. An effective irrigation management strategy is to maintain soil moisture in the top 50 cm between field capacity and 60% of field capacity.

In the example in Table 5, there is only 18 mm of readily available water in the 0 to 25 and 25 to 50 cm depths, for a total of 36 mm/50 cm. When the soil is at field capacity, there is only 36 mm of readily available water.

As the available water is being used by the crop, it must be replaced to ensure optimum yield potential. If durum is using 7 mm of water per day, it would take 5 days to use up the readily available water. But, if durum is using 9 mm of water per day, it would take only 4 days to use up the readily available water.

TABLE 5. *Example of a soil profile with loam and clay loam textured soil at different depths, the amount of total available water for each soil depth based on texture (from Table 1) and the amount readily available water in each depth assuming 40% of water is readily available (Source: R. H. McKenzie).*

SOIL DEPTH (cm)	GROSS WATER APPLICATION (mm)	EXPECTED WATER LOSSES FOR ONE CIRCLE (mm)	NET WATER APPLICATION (mm)
0 to 25	Loam	45	18
25 to 50	Loam	45	18
50 to 75	Clay loam	50	20
75 to 100	Clay loam	50	20
Total		190	86

Irrigation Management and Fusarium Head Blight

Irrigation management is a very important strategy for fusarium head blight (FHB) control. Pivot irrigation is frequently used for durum, which allows light frequent water application. Pivot irrigation is excellent for optimizing production, but can increase the potential infection of FHB during flowering of durum, by increasing humidity in the crop canopy. For this reason, irrigation should be avoided during the period of flowering to reduce humid conditions in the crop canopy.

It is important to know when flowering begins and ends for durum wheat, which typically begins to flower about 3 days after the head has fully emerged (heads have cleared the flag leaf collar) and will last for about 3 to 5 days. Heads on tillers will emerge a few days after the main stem and will also flower for 3 to 5 days. Using high seeding rates will reduce tillering and increase uniformity of heading . Therefore, irrigation of a durum crop of durum needs to be terminated for 8 to 10 days depending on field conditions and the timing of main stem and tiller head emergence.

As mentioned previously, durum is at peak water use at the flowering growth stage, using between 7 and 8 mm/day and can peak at 10 mm/day of water, depending on evapotranspiration conditions including maximum air temperature and wind speed. Termination of irrigation at peak water use means irrigation must be carefully managed leading up to and after flowering. Over 10 days, a cereal crop will use 70 to 90 mm of water. Therefore, it is important to know the water holding capacities of the soils on your land and have the 50 to 100 cm of soil in the root zone at field capacity just before head emergence.

A cereal crop grown on a loamy sand or sandy loam textured soil would likely run out of readily available water over 10 days before irrigation is re-started, if only 40% of water is used as the safe depletion. On sandy soils it is difficult to go 10 days without irrigation and not suffer some loss in yield. Normally, durum grown on loam or clay loam soils can go 10 days without significantly impacting yield, if the 50 to 100 cm zone is at field capacity just before flowers starts.

Summary

To manage irrigation water, it is important to know the daily crop water use and to check soil moisture weekly early in the growing season and then every three to four days during peak water use to ensure soil moisture is maintained between field capacity and safe depletion point, which is about 60% of field capacity or 40% allowable depletion. If this is successfully done during the growing season, optimum yield of durum wheat can be achieved.

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9. SMART FARMING

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Photo credit: SOUTH WEST TERMINALS

Smart Farming represents the application of modern information and communication technologies (ICT) into agriculture. The information and communication technologies of the internet are contributing to the professionalization of the agricultural world based upon the combined application of ICT solutions such as precision equipment, the Internet of Things (IoT) (https://en.wikipedia.org/wiki/Internet_of_things), sensors and actuators, global-positioning systems (GPS) (https://en.wikipedia.org/wiki/Global_Positioning_System) , global navigation satellite system (GNSS) (https://www.gsa.europa.eu/european-gnss/what-gnss), Big Data (https://en.wikipedia.org/wiki/Big_data) , Unmanned Aerial Vehicles (UAVs, drones), robotics, etc. Precision agriculture is a component of Smart Farming. Precision agriculture (PA), satellite farming or site-specific crop management (SSCM) (https://www.ndsu.edu/fileadmin/soils/pdfs/1176.1.pdf), is a farm management concept based on observing, measuring and responding to inter and intra-field variability in crops, with the goal of optimizing returns on inputs while preserving resources. Smart Farming has a potential to deliver a more productive and sustainable agricultural production system, based on a more precise and resource-efficient approach. In Canada and the USA possibly up to 80% of farmers use some kind of Smart Farming Technology.

From the farmer's point of view, Smart Farming should provide the farmer with added value in the form of better decision making or more efficient operations and management.

In this sense, Smart Farming is related, to three interconnected technology fields addressed:

- Management Information Systems: Planned systems for collecting, processing, storing, and disseminating data in the form needed to carry out a farm's operations and functions including the information about varieties in Seed Guides, disease and insect forecasts, market information
- Precision Agriculture: Management of spatial and temporal variability to improve economic returns following the use of inputs and reduce environmental impact. It includes Decision Support Systems (DSS) for whole farm management with the goal of optimizing returns on inputs while preserving resources, enabled by the widespread use of GPS, GNSS, aerial images by drones and the latest generation of hyperspectral images provided by Sentinel satellites, allowing the creation of maps of the spatial variability of as many variables as can be measured (e.g. crop yield, terrain features/topography, organic matter content, moisture

PRIMARY PRODUCER'S ON-FARM STORAGE
Photo credit: R.M. DEPAUW

levels, nitrogen levels, etc). This includes the Geno type x Environment x Management interaction (GxExM) and 4R's of nutrient management

- Agriculturwal automation and robotics: The process of applying robotics, automatic control and artificial intelligence techniques at all levels of agri cultural production, including farmbots and farmdrones.

Accessing information on the global supply and disposition of durum wheat, the futures market, and contracting is all part of the information and communications technologies of the internet. Smart Farming includes access to this global information. Smart Farming applies not only to large operations but all sizes of farming operations, family corporations and unincorporated family farms. Smart Farming can also provide great benefits in terms of environmental issues, for example, through more efficient use of water, or optimization of treatments and inputs, reduction of crop losses and wastes. The outcome of Smart Farming is the professionalization of agriculture.

Adapted from: Smart Farming Thematic Network https://www.smart-akis.com/index.php/network/what-is-smart-farming/

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10. INTEGRATED WEED MANAGEMENT TO MINIMIZE YIELD LOSSES

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Introduction

Diversification of weed management tools can reduce the selection pressure imposed on a weed population by any one tool, and reduce the probability that resistant weeds will flourish. Herbicide resistance (HR) is the most common example of a selection pressure resulting in the evolution of weed populations to include weed biotypes that resist a weed management tool. An integrated weed management (IWM) program is necessary to mitigate or manage HR weed populations. In general, weed management tools are categorized into four groups: cultural, physical, biological, and chemical.

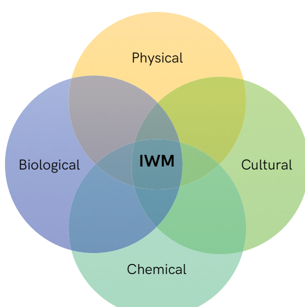

***FIGURE 1.** Diagram showing the four components to an integrated weed management (IWM) program.*

An IWM program is comprised of at least one weed management tool from more than one of these categories. While the rotation or combination of herbicide modes of action (MOA) (i.e., herbicide rotation or tank mixing) can delay HR in weed populations, both of these tools are chemical in nature – generally include increased herbicide use – and when implemented alone comprise an integrated herbicide management program; not an IWM program. A reduction in herbicide use is the best way to reduce selection pressure for HR weeds. The integration of non-chemical tools for weed management into herbicide-dominant weed management programs can facilitate a reduction in herbicide use, contributing to the sustainability of durum production in Western Canada.

Non-chemical Weed Management

In Western Canada, few research studies have been conducted on non-chemical weed management in durum. The research conducted to-date indicates that the competitive ability of durum with weeds is similar to other wheat classes (e.g., Beres et al. 2010), however, some differences in competitive ability may exist due to dissimilarity in growth, development, and resource allocation among wheat classes.

Cultural Weed Management

Cultural weed management includes preventative measures used to increase the crop's ability to compete with weeds. These tools are important in wheat production because wheat is considered one of the least competitive cereal grain crop species in Western Canada, and implementing these tools in combination tends to amplify their benefits for weed management. There are many cultural tools available for weed management in durum, and some of these tools already could be implemented without realization (and potentially also without incurring additional cost). Examples of cultural weed management include: crop rotation, crop diversity, crop life cycle diversity, cultivar selection, increased seeding rate, decreased row spacing, row orientation, seeding early, fertility management (fertilizer source, timing, rate and placement), cover crops, intercrops, mulches, and also using clean certified seed. Many of these tools are also beneficial for weed management in other wheat classes and crops (Harker et al. 2017). Plant height of durum wheat is the largest contributing factor to its ability to compete with weeds (Beres et al. 2010; Zerner et al. 2008). Tall durum cultivars can mitigate potential yield loss due to weeds and also reduce weed seed production compared with short cultivars. Plant height is more important for durum wheat than other wheat classes because early crop vigour, tiller number, and canopy leaf area do not influence the competitive ability of durum wheat to the same extent as bread wheat classes (Zerner et al. 2008). Thus, growing a tall cultivar is the most important factor for increasing the ability for durum to compete with weeds.

Recent research in Saskatchewan suggested that the yield potential of durum wheat could only be reached if durum seeding rates were increased from current recommendations (Isidro-Sánchez et al. 2017). In weed-free conditions, durum wheat yielded the greatest at seeding rates between 25 and 35 seeds per sqft (272 and 380 seed per sqm) the maximum seeding rates used in their study. Also, in their study leaf area index (LAI) increased linearly as seeding rate was increased. Greater LAI at population densities of durum wheat would increase light interception by the wheat canopy and decrease the quality of light available to weeds beneath the canopy; contributing to decreased competition from weeds that escape herbicide application. Preliminary research in South Australia also showed that increasing the seeding rate of durum wheat from 10 to 20 to 30 seeds per sqft (100 to 200 to 300 seeds per sqm) resulted in increased yield and reduced yield loss in the presence of competing weeds (Goss and Wheeler 2015).

Physical Weed Management

Physical weed management disrupts the weed life cycle using mechanical disturbance, and physical tools such as tillage were the basis of weed management prior to herbicides. In Western Canada, durum wheat is primarily grown in areas that utilize zero- or minimum-tillage to conserve soil moisture, making soil disturbance prior to or within durum production rather impractical. Aside from tillage, physical weed management also can be achieved by mowing, clipping (e.g., the CombCut®; (http://www.justcommonsense.eu/en/), or implementing harvest weed seed control [HWSC; e.g., narrow windrow burning, chaff lining, chaff carts, direct baling, or seed milling (look up the Harrington Seed Destructor, (http://www.ihsd.com/; or the Seed Terminator, https://www.seedterminator.com.au/) (Walsh et al. 2017)]. In durum, using a CombCut® to clip weeds within the crop canopy could be an effective option to remove broadleaf weeds that escape herbicide application, while HWSC can reduce the viability of weed seeds ejected by the combine at harvest (Tidemann et al. 2017), thereby depleting additions of viable weed seeds to the soil seed bank.

Biological Weed Management

Biological weed management relies on living organisms to manage weeds, and generally is underutilized in cropping systems due to the complexity of implementation. However, simple tools such as grazing of weeds or promoting biological predation of weed seeds should be implemented in cropping systems to reduce weed populations in durum without additional herbicide use. Natural seed predators [e.g., Carabid beetles (Kulkarni et al. 2015)] can deplete weed seeds in the soil seed bank and therefore should be promoted. Generally, weed seed predation is greatest near the soil surface and decreases with the depth of seeds in soil. Zero- or minimum-tillage may assist seed predators with access to weed seeds in the soil seed bank, allowing for greater depletion of the weed seed bank without incurring additional cost.

Chemical Weed Management

Herbicide Selection, Efficacy and Phytotoxicity

Generally, most herbicides that are registered on spring wheat are also registered on durum wheat; however, there are exceptions. For example, Axial (active ingredient: pinoxaden) is registered in spring wheat; however, durum wheat does not exhibit adequate tolerance to this herbicide at the rates registered in spring wheat. Growers wishing to use pinoxaden have to use the co-formulated product called Traxos, which contains a lower concentration of pinoxaden plus clodinafop propargyl (active ingredient in Horizon, Foothills, etc.). The other product that is registered in spring wheat but not durum wheat is Focus (carfentrazone and pyroxasulfone). Soltani et al. (2012) reported that pyroxasulfone application caused unacceptable injury in durum wheat, oat, and barley, while spring wheat tolerance was acceptable.Thus, a grower should not assume that a herbicide registered for use in spring wheat can be used safely on durum wheat.

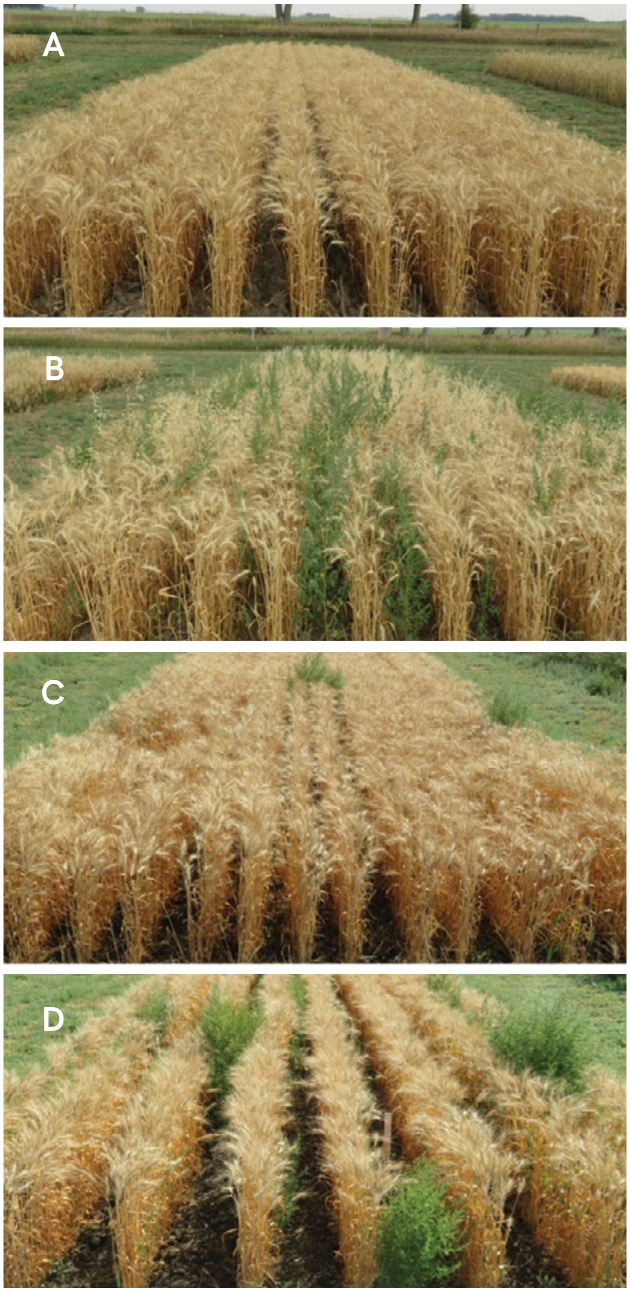

FIGURE 2. *A) Hard red spring wheat (HRSW) Lillian 200 viable seeds per 10.8 sq ft (1 sqm) 12 inch row spacing post-emergence herbicide; B) HRSW Lillian 200 viable seeds per 10.8 sq ft (1 sqm) 12 inch row spacing no post-emergence herbicide; C) Glyphosate resistant kochia in HRSW AAC Brandon, 400 viable seeds per 10.8 sq ft (1 sqm) 9 inch row spacing post-emergence herbicide; D) Glyphosate resistant kochia in HRSW AAC Brandon, 200 viable seeds per 10.8 sq ft (1 sqm) 18 inch row spacing post-emergence herbicide. Photo credit: C.M. Geddes AAFC-Lethbridge*

Herbicide options registered for use in durum in the Prairie Provinces are available in Guide to Crop Protection (http://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/crop-guides-and-publications/guide-to-crop-protection) and Table 1.

Many durum growers also grow pulse crops such as lentil in their crop rotations. The cereal phase of the rotation can be an opportune time to manage hard-to-control and herbicide resistant weed species that are a problem in pulse crops (e.g., Group 2 resistant kochia, wild mustard, etc.). Growers have the opportunity to use efficacious products from Groups 4, 6, and 27 to manage these weeds; however, they need to be aware of the potential for some of these products to persist in the soil and injure sensitive rotational crops. Durum growers should consult herbicide labels for re-cropping restrictions if they are considering using the following active ingredients in durum wheat: clopyralid, flucarbazone, halauxifen, and pyrasulfotole.

Maximum Residue Limits (MRLs) are the level of pesticide residues permitted in the harvested crop, including imported food. Each country establishes its own MRLs, including Canada. MRLs are set for each pesticide registered for use in Canada. Sometimes MRLs in Canada differ from those in export markets or may not exist in export markets for certain pesticides. Durum wheat exports may be tested by importing countries for residues of unregistered products, excess residues of registered products or unregistered uses. Producers are encouraged to talk to their grain buyer before using a new registered product to ensure they understand any export restrictions. Up to date information on MRL's, herbicide products, and market risks is available on the Keep it Clean! website (https://keepingitclean.ca/).

Spray Application Methods

A typical weed control application in durum will likely target both broadleaf and grassy weeds. Whenever grassy weeds are part of the mix, their relatively poor ability to intercept and retain the larger spray droplets needs to be considered. As a result, a Medium to Coarse spray quality, as described in nozzle manufacturer's catalogues, is most appropriate. These spray qualities are typically achieved with an intermediate air-induced nozzle such as the Air Bubble

Jet, the Greenleaf AirMix, Hypro GuardianAIR (also known as John Deere LDA), the TeeJet AIXR, and Wilger MR and SR tips. Wilger tips are often used with Pulse-Width Modulation such as Case AIM Command, Capstan Pinpoint, or Raven Hawkeye. With these tips, an operating pressure of about 60 to 70 psi results in a spray that will provide good retention and coverage on both grassy and broadleaf species.

When only broadleaf species are to be targeted, an applicator may have additional opportunities to use coarser sprays (Coarse to Very Coarse) to reduce drift. Most broadleaf plants have a better capability to capture larger droplets, due to a combination of easier-to-wet surfaces and more horizontal leaf orientation. The broadleaf weed spectrum should be assessed for those characteristics before making a spray quality decision, as there are exceptions, such as kochia and lamb's quarters. Similar spray tips as above are recommended, but these can now be operated at pressures down to 40 psi to manage drift without harming weed control. Additional nozzles that are recommended include the Greenleaf TurboDrop, Hypro and John Deere ULD, TeeJet AI or AITTJ60, as these produce Coarse to Very Coarse sprays at about 60 psi.

For broadleaf weeds, additional consideration should be given to the mode of action (MOA) of the herbicide. Systemic products, such as Group 2 and 4, are better suited to the Very Coarse sprays than contact products such as Group 5, 6, and 27. Contact products should be applied similar to grassy herbicide products, by increasing spray pressure and/or water volumes.

For all nozzles, set boom heights to ensure a minimum overlap of 100%. This means the spray pattern width at target height should be twice the nozzle spacing. Each nozzle recommended above has a unique spray angle, and a visual check is necessary to ensure this overlap requirement is met. Application volumes of 7 to 10 gpa should be maintained to provide the best performance for coarser sprays.

Allelopathy

Plants often release secondary metabolite chemicals into the environment, which can contribute to the suppression of neighboring weeds (i.e. allelopathy). For example, wheat plants can release benzoxazinoid chemicals, contributing to the suppression of germination and development of weed seeds and seedlings. The allelopathic potential of wheat, however, varies among cultivars, and little information is available to indicate that durum wheat lines retain the ability to suppress weeds using allelopathy (Fragasso et al. 2013).

Problem Weeds in Durum

In general, weed control using an efficacious herbicide imposes a large selection pressure on weed populations, contributing to HR weeds, in the absence of additional weed management. In Western Canada, nine of the top ten most abundant weed species in durum fields have populations with confirmed HR (Table 2; Heap, 2017). The number of herbicide MOA to which these weed species have known resistant biotypes ranges from six to zero and in the order of wild oat (6 MOA) > green foxtail, volunteer canola, kochia, wild mustard (3 MOA) > stinkweed, wild buckwheat, lamb's quarters, Russian thistle (1 MOA) > Canada thistle (non-HR) (Heap, 2017).

Based on Prairie Weed Surveys conducted from 2009 on, the top five most abundant weeds in durum are: green foxtail, wild oat, volunteer canola, stinkweed and wild buckwheat (Table 2). Three of these weeds are annual broadleaf weeds, while two are annual grass species. The abundance of annual weeds is not surprising considering durum is typically grown in rotation with other spring annual crops. A spring annual rotation selects for weeds with similar life cycles. Interestingly, three of these weeds (green foxtail, wild oat, wild buckwheat) have been the top three most abundant weeds in all crops in the prairies since the 1970s.

Both green foxtail and wild oat are spring annuals that cause yield loss in durum. The extent of yield loss caused by green foxtail depends on relative timing of emergence for both weeds and weather conditions post-emergence (Beckie et al. 2012; Douglas et al. 1985). Both green foxtail and wild oat seeds exhibit dormancy at maturity (for approximately 10 weeks and 1 year, respectively) and have persistent seed banks. Green foxtail seeds persist in the soil for longer, particularly when buried at depth. Both wild oat and green foxtail have populations resistant to group 1 and group 2 herbicides, while green foxtail has additional resistance to group 3 herbicides, and wild oat has additional resistance to groups 8, 14, 15, and 25 (Heap 2017).

TABLE 1. *Herbicides registered for use in durum wheat in the prairie provinces in 2018 (Adapted from the Guide to Crop Protection 2018)* [a]

HERBICIDE	HERBICIDE GROUP/MOA	BARNYARD GRASS	FOXTAIL, GREEN	FOXTAIL, YELLOW	ANNUAL BROMES	VOLUNTEER CORN	WILD OATS	BUCKWHEAT, WILD	CATCHFLY, NIGHT-FLOWERING	CHICKWEED	CLEAVERS	COCKLEBUR	DANDELION	FLIXWEED	HEMP-NETTLE	KOCHIA	LAMB'S QUARTERS	MALLOW, ROUND-LEAVED	MUSTARD, WILD	PIGWEED, REDROOT	RUSSIAN THISTLE	SHEPHERD'S PURSE	SMARTWEED	SOW-THISTLE, PERENNIAL	STINKWEED	THISTLE, CANADA	VOLUNTEER FLAX	VOLUNTEER MUSTARD, CANOLA	VOLUNTEER SUNFLOWERS
2,4-D	4									•		•	•[1]	•		•	•		•	•	•	•	•		•	S		•	S
Avadex	8						•																						
Barricade II	2,4							•	•	•	•			•	•	•	•	•	•	•	•		•	•	•	•	•	•	
Bromoxynil	6							•				•				•	•		•[5]	•[5]	•		•		•[1]				
Bromoxynil/2,4-D	4,6							•	•			•		•		•	•		•	•	•	•	•		•			•	•
Bromoxynil/MCPA	4,6							•	•			•		•		•	•		•	•	•	•	•	T	•	T		•	•
Bromoxynil + MCPA + Fluroxypyr	4,6							•[5]	•[5]	•[5]	•[5]	•[5]			•[5]	•	•		•	S	•[5]	•[5]	•[5]		•[5]	T	•[5]	•[5]	•[5]
Cirpreme/MCPA	2,4							•		•	•	•	•	•	•	S	•	•	•	•		•	•	•	•	•	•	•	•
Clodinafop	1	•	•	•			•																						
Curtail M	4							•				•	•[1]	•		S	•		•	•[5]		•	•[5]	•	•	•		•[5]	•
Dicamba + MCPA/2,4-D	4							•			•	•		•	•[3]	•	•		•	•	•	•	•	T	•	T		•	S
Dicamba/Mecoprop/ MCPA	4							•	•		•			•	•	•	•		•	•	•	•	•	T	•	T		•	•
Dichlorprop/2,4-D	4							•	•[5]			•		•		•	•	•	•	•	•	•	•	T	•	T		•	•
DyVel	4							•			S	•		•	•	•	•		•	•	•	•	•	T	•	T		•	•
DyVel DSp	4							•			S	•		•		•	•	S	•	•	•	•	•	T	•	T		•	•
Enforcer D	4,6							•[5]	•		•		•[5]		•	•	•	•[5]	•	•[5]	•[5]	•	•		•	S	•[5]	•	
Enforcer MSU	2,4,6							•	•	•	•	•		•	•	•	•		•	•	•	•	•		•	T	•	•	•
Everest GBX	2,4		•				•	•			•					•			•	•		•	•				•	•[4]	
Fenoxaprop	1	•	•	•			•																						
Florasulam + 2,4-D	2,4							•		•	•	•	•[2]	•	S		•		•	•	•	•	•	S	•	S		•	•
Florasulam + *Curtail M*	2,4							•		•	•		•[2]	•[1]	•		•		•	•		•	•	T	•	•		•	
Florasulam + MCPA	2,4							•		•	•		•[2]	•	•		•		•	•		•	•	T	•	T		•	•
Flucarbazone	2		•				•												•	•		•	•					•[4]	
Fluroxypyr + 2,4-D	4							•		S	•	•	•[1]	•	S	•	•	•	•	•	•	•	•	S	•	S	•	•	•
Fluroxypyr + MCPA	4							S			•	•		•	•	•	•		•	•		•	S		•		•	•	•
Fortress MicroActiv	3,8		•				•								S	S			S	S									
Harmony K	1,2,4	•	•	•			•	•		•				•		•[8]	•		•	•	•	•	•		•			•[4]	•
Harmony SG	1,2	•	•	•			•	•		•				•			•		•	•	•	•	•		•			•[4]	•
Hat Trick	4							•		•	•		•		•	•	•			•		•		•		•			
Imazamethabenz	2						•	•											•						•			•[4]	
Infinity	6,27							•		•	•		S	•	•	•	•	S	•	•	•	•	•	S	•	S		•	
Linuron + MCPA amine	4,7							•		•		•		•	•		•		•	•		•	•		•				
MCPA	4											•		•	S	•	•		•	•		•	•		•				
Mecoprop-p	4									•	•						•		•										
Metribuzin	5								•	•					•		•		•	•	•		•		•			•	

TABLE 1 Continued. *Herbicides registered for use in durum wheat in the prairie provinces in 2018 (Adapted from the Guide to Crop Protection 2018)* [a]

HERBICIDE	HERBICIDE GROUP/MOA	BARNYARD GRASS	FOXTAIL, GREEN	FOXTAIL, YELLOW	ANNUAL BROMES	VOLUNTEER CORN	WILD OATS	BUCKWHEAT, WILD	CATCHFLY, NIGHT-FLOWERING	CHICKWEED	CLEAVERS	COCKLEBUR	DANDELION	FLIXWEED	HEMP-NETTLE	KOCHIA	LAMB'S QUARTERS	MALLOW, ROUND-LEAVED	MUSTARD, WILD	PIGWEED, REDROOT	RUSSIAN THISTLE	SHEPHERD'S PURSE	SMARTWEED	SOW-THISTLE, PERENNIAL	STINKWEED	THISTLE, CANADA	VOLUNTEER FLAX	VOLUNTEER MUSTARD, CANOLA	VOLUNTEER SUNFLOWERS
Metsulfuron	2									·				·	·	·	·		·	·	·	·	·	·[8]	·	·[8]		·	
Momentum	4							·			·					·										·	·		
Optica Trio	4							·		·	·					·	·		·	·					·	T		·	
Paradigm	2,4							·		·	·		·[7]		S	S	·		·	·		·	·	S	·	S[7]	·	·	
Predicade	2,4	·	·	·			·	·	·	·	·		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	
Quinclorac	4,26[6]	·	·								·													S			·		
Signal SFU	1,2,4	·	·	·			·	·		·	·			·	·	·	·	S	·	·	·	·		S	·	S	·	·	·
Simplicity / Simplicity GoDri	2	S	S	S	·[9]		·	S		·	·		S	·	·			·		·	S	·	·		·	S		·[4]	
Traxos	1	·	·	·			·																						
TraxosTwo	1,4	·	·	·			·	·		S	·	·	·[1]	·	S	·	·	·	·	·	·	·	·	S	·	S	·	·	·
Varro	2	·	·	S	S		·	·			·				·		S	S	·	·	S	·			·			S	
Velocity m3	2, 27	·	·	S	S		·	·		·	·		S	·	·	·	·	S	·	·	·	·	·	S	·	S		·	

[a] *The top ten most abundant weeds in durum are highlighted in grey; · Control; S – Suppression; T - Top growth control;*
[1] *Spring seedlings only;* [2] *Spring seedlings and overwintered rosettes;*
[3] *MCPA K mixes only;*
[4] *Will not control CLEARFIELD canola varieties;*
[5] *Controlled at the higher rates;*
[6] *Group 4 mode of action on broadleaves and group 26 mode of action on grasses;*
[7] *Up to 30 cm tall or across;*
[8] *Less than 15 cm diameter.*
[9] *Controls Japanese brome, suppresses downy brome*

TABLE 2. *The mean frequency, uniformity, density and relative abundance of the top ten weed species in 389 durum fields in Alberta and Saskatchewan, surveyed between 2009 and 2017* [a]

RANK	SPECIES	FREQUENCY [b]	UNIFORMITY [c]	DENSITY [d]	RELATIVE ABUNDANCE [e]
		.... %	....	-no. plants per sqm	
1	Green foxtail	29	47	24	53
2	Wild oats	28	32	8	27
3	Volunteer canola	17	35	23	27
4	Stinkweed	16	32	19	22
5	Wild buckwheat	37	21	2	22
6	Kochia	25	18	2	14
7	Lamb's quarters	16	26	4	12
8	Canada thistle	21	15	2	12
9	Russian thistle	14	29	5	11
10	Wild mustard	10	35	7	9

[a] *Preliminary data provided by Julia Leeson, Weed Monitoring Biologist, Agriculture and Agri-Food Canada, Saskatoon Research and Development Centre, Saskatoon, SK, CA.*
[b] *The mean percentage of durum fields in which each species occurred.*
[c] *The mean percentage of sampled quadrats in which each species occurred in durum fields.*
[d] *The mean plant density of each species in durum fields in which the species was present.*
[e] *An index based on the frequency, uniformity and density of occurrence of each weed species in durum fields.*

TABLE 3. *Recommended resources for further information*

TOPIC	SOURCE/INFORMATION/WEBSITE
BMPs for sprayer operation	http://sprayers101.com/
Chemical weed management (Alberta)	Crop Protection 2017. Brook, H., and Cutts, M. (eds.): Alberta Agriculture and Forestry, Edmonton, AB, CA. 586 pp. Available online at: http://www.agriculture.alberta.ca/bluebook/
Chemical weed management (Manitoba)	Guide to Crop Protection 2017. Crop Industry Branch, Manitoba Agriculture, Carman, MB, CA. 720 pp. Available Online at: https://www.gov.mb.ca/agriculture/crops/guides-and-publications/
Chemical weed management (Saskatchewan)	Guide to Crop Protection 2018. Saskatchewan Ministry of Agriculture, Regina, SK, CA. 720 pp. Available Online at: http://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/crop-guides-and-publications/guide-to-crop-protection
CombCut®	http://www.justcommonsense.eu/en/
Integrated Harrington Seed Destructor (iHSD®)	http://www.ihsd.com/ or http://ahri.uwa.edu.au/ihsd/
Herbicide-resistant weeds	https://ahri.uwa.edu.au/ihsd/
IWM strategies	http://www.weedsmart.org.au/
IWM in wheat	Harker, K.N., O'Donovan, J., and Tidemann, B. (2017) Integrated weed management in wheat cultivation. Chapter 21 in: Achieving sustainable cultivation of wheat, Volume 1. Langridge, P. (ed.): Burleigh Dodds Science Publishing Limited. 23 p.
Maximum Residue Limits Keep it Clean	https://keepingitclean.ca/
Non-chemical weed management	Non-chemical weed management: principles, concepts and technology. Upadhyaya, M.K., and Blackshaw, R.E. (eds.): CAB International, Wallingford, UK. 239 pp.
Research on IWM in durum (Australia)	http://sagit.com.au/projects/a-new-approach-to-grass-weed-control-for-durum-wheat/ or http://www.hartfieldsite.org.au/pages/resources/trials-results/2014-trial-results.php
Seed Terminator	https://www.seedterminator.com.au/
Weed biology	Weeds of Canada and the Northern United States. Royer, F., and Dickinson, R. (eds.): University of Alberta Press. Edmonton, AB, CA. 434 pp.
Weed resistance management	http://ahri.uwa.edu.au/

Volunteer canola is an annual weed, typically introduced by large seed losses at canola harvest, resulting in glyphosate, glufosinate, or imidazolinone resistant populations (Gulden et al. 2008). Some volunteer canola seeds germinate and emerge in the fall after canola harvest; however, few seedlings survive to maturity (Geddes 2017). Seed dormancy and persistence of volunteer canola is tied to environmental conditions, but seeds in the soil seedbank can often remain viable for greater than three years.

Wild buckwheat is a spring annual weed. In addition to crop competition, wild buckwheat causes significant crop lodging, grain sample contamination and harvest difficulties. Wild buckwheat is less affected by increased crop seeding rates because of its climbing ability. Its ability to climb up and through the crop canopy allows it to capture light even in highly competitive environments (Hume et al. 1983). Wild buckwheat seeds exhibit dormancy at maturity and typically are stimulated to germinate by crop planting. The majority of wild buckwheat seeds germinate within the first year in the seed bank, but can survive for up to five years. In Canada, there are populations of wild buckwheat resistant to group 2 herbicides (Heap 2017).

Stinkweed has the ability to grow as a spring or winter annual. Like the other species, it is known to cause yield losses in many crops (Warwick et al. 2002). It has a persistent seed bank and is a prolific seed producer. Stinkweed seeds can maintain viability for over 20 years in the soil. In Canada, there are confirmed cases of group 2 resistant stinkweed (Heap 2017).

With all of the top five weeds being annual species, diversifying crop life cycles can aid in their management. Most of the species are spring annuals, so including winter cereals in rotation with durum may help in controlling those populations. An exception is stinkweed, which can also grow as a winter annual. Mixed farming systems provide more opportunity to manage annual weeds through seeding perennial forage or annual silage crops. For example, early cut silage can effectively manage wild oat populations (Harker et al.

2016). Increased crop seeding rates can be effective in managing wild oat and stinkweed. Soil disturbance shortly following canola harvest has been shown to reduce population densities of volunteer canola originating from crop harvest losses (Geddes and Gulden 2017). Green foxtail is highly responsive to nitrogen fertilizer so appropriate fertilization techniques can facilitate management of this weed. As all of the top five weeds exhibit herbicide resistance, it is important to use multiple herbicide MOA in combination with non-chemical weed management tools, where possible, to reduce the selection pressure for herbicide resistance. It is important to note that more than one MOA must be effective on the weed to reduce the selection pressure for resistance. For example, if a group 2 plus 4 herbicide or herbicide tank-mix is used to control a weed that has group 2 herbicide resistance, only the group 4 MOA is active on the weed, resulting in increased selection pressure for group 4 resistance.

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11. DISEASE MANAGEMENT TO MINIMIZE CROP LOSSES AND MAXIMIZE QUALITY

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Introduction

Durum wheat is affected by a range of infectious diseases, from major to minor. The majority of diseases are caused by fungi that are transmitted by spores, other fungal structures, or infested plant debris. Some diseases affect yield, some affect the quality of the grain, and others affect both. Awareness is the number one factor in managing disease. Crop monitoring and accurate disease identification are critical to implementing appropriate disease management strategies. Knowledge of each particular disease capable of affecting the crop is essential to developing effective management. By having a strategy, the best means of control can be implemented

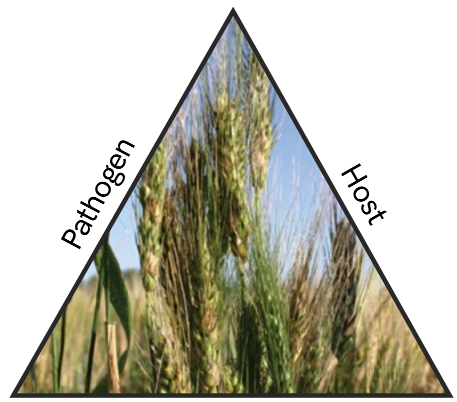

FIGURE 1. *The amount of disease can be visualized as a triangle of conditions required for its development: pathogen, host, and environment.*

Strategies for disease control

Among the principles with the greatest impact on disease management are selection of a resistant variety, crop rotation to allow time for the disease propagules (structures capable of reproducing the organism) to degrade before the next durum crop, and application of chemical pesticides to control the pathogen. Further options include timing crop development to escape the disease, management of crop residues to facilitate the breakdown of disease infectious structures, and sanitation to minimize introducing or promoting the spread of disease. A useful way of thinking about disease management is to consider the requirements for disease to be expressed, namely the durum plant as host, the disease-causing pathogen, and the conditions or environment in which the durum plant and pathogen exist. These key requirements for disease are related and can be visualized to form a disease triangle as shown in Figure 1.

The amount of disease can be minimized by manipulating the durum host, the pathogen, or the environment, but the greatest gains can be made by manipulating all three factors (Figure 2). Bolstering the durum host plant can reduce the level of disease. Selection of the most resistant variety to a problematic disease can be an effective low-cost option for disease control. Plants that are grown with a balance of nutrients are able to cope with disease pressure. Provincial Seed Guides (http://publications.gov.sk.ca/documents/20/96889-Varieties%20of%20Grain%20Crops_2018.pdf) list a wealth of disease information and should be consulted when choosing a variety with the best combination of resistance for a particular farm. Limitations placed on the pathogen will reduce disease. As examples, a fungicide may be applied to a crop to limit the amount of infection, or crop rotation may be used to reduce the amount of infecting structures of the pathogen. In the case of fungicide use, proper identification of the disease is necessary to match an effective product, because not all products are effective against all diseases. The crop environment also may be manipulated to favour the host or hinder the pathogen. For example, avoiding irrigation at the susceptible stage of the crop (flowering) to Fusarium can reduce the level of Fusarium head blight.

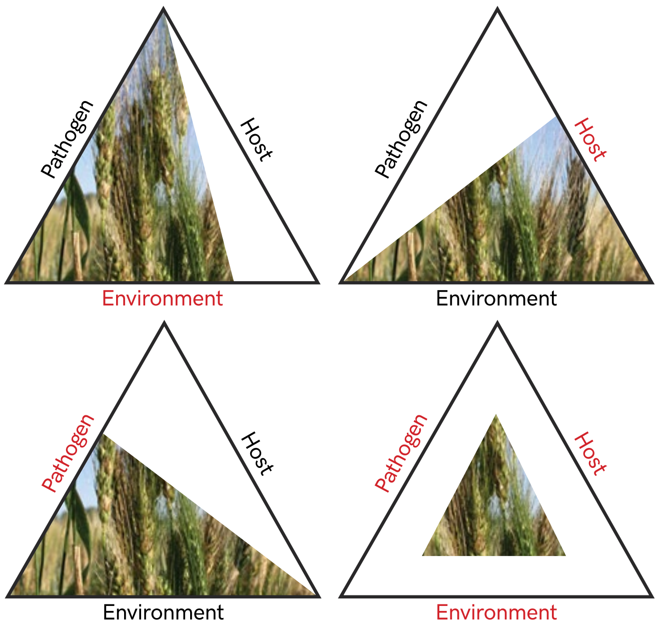

FIGURE 2. *Modification of the environment, actions to bolster each durum host plant, and limitations placed on the pathogen are ways to reduce disease (represented by the triangular picture within the black triangle). By manipulating all three, disease is more effectively reduced.*

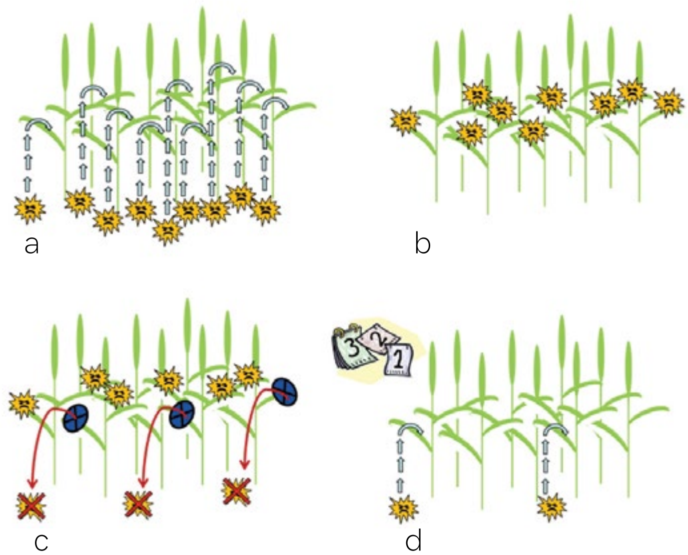

FIGURE 3. *The effect of quantity of infectious structures on the amount of disease. Many fungal spores (a) available to infect all plants will cause much disease (b). By using the most resistant durum variety available (c) (i.e. moderately susceptible instead of susceptible) the quantity of infectious structures will be reduced, decreasing the amount of disease in the next cropping cycle (d).*

An important fourth element of disease management is time, particularly as it relates to generation time of the disease pathogen. In this context, thinking about the number of disease infectious structures available to start disease is important. The greater the number of infective structures the more completely the crop will be affected (Figure 3). By reducing the level of disease in a durum crop in one year, there will be fewer infective structures to produce disease the next time the durum crop is grown on the same field. The number of viable infective structures can be reduced by using the most resistant variety available, even a moderately susceptible (MS) variety is better than a susceptible (S) one. Extending the time between durum crops on the same land will also reduce the number of viable infectious structures.

Managing individual diseases

Fusarium head blight (FHB, Figure 4) requires a multipronged approach to control. (https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/disease/fusarium-head-blight). For optimum control, a seed source with a minimum of affected seeds of the most resistant cultivars should be grown on fields that have been rotated out of durum for at least two years, monitor for the disease and consult Fusarium head blight risk maps. Risk maps are available in June and July to help farmers with making decisions whether or not to spray a fungicide for FHB control, for example in Saskatchewan Sask Wheat Development Commission hosts an internet risk map resource (http://www.saskwheatcommission.com/producer-info/fusarium-risk-assessment-map/).

There is no relationship between Fusarium damaged kernels used for planting and the probability of Fusarium head blight infection in the resulting crop. Grain grade does not necessarily determine suitability for planting. If the disease has been detected in the area in the past, weather conditions should be monitored at heading and if conditions are considered favourable, that is, with the presence of moisture or high humidity at the start of flowering, an appropriate fungicide should be applied. The fungicide should be applied at the start of flowering, too early being better than too late.

A forward directed nozzle that delivers a medium to coarse droplet at least 10 to 20 gpa (45 to 90 liters) water will provide some level of control. By seeding the durum crop with a high seeding rate, the crop will head more uniformly making it easier to time a fungicide application.

Diseases such as seedling blight and root rot can be reduced through the application of a seed treatment and by using sound disease free seed. Some examples of seed-borne diseases include common bunt, loose smut, the tan spot causing pathogen, and the Septoria leaf blotch causing pathogen. Seed-borne pathogens that cause root rot include Fusarium species and that of black point. Common bunt spores are borne on the surface of the seed, while loose smut and root rotting pathogens reside within the seed. Seed to be used for planting can be analyzed for the presence of individual diseases using a seed testing lab. The Guide to Crop Protection (https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/crop-guides-and-publications/guide-to-crop-protection) provides information on the use of fungicides for the control of diseases. Always refer to the product label for application details and precautions.

Loose smut (Figure 5) and common bunt (Figure 6) may be controlled by an appropriate seed treatment or by planting uninfested seed in the case of bunt i.e. no common bunt spores on the seed surface, or uninfected seed in the case of loose smut i.e. the loose smut pathogen is not present within the embryo of the seed. Cultivars resistant to these two diseases are also available.

To minimize ergot (Figure 7), seed free of ergot bodies should be used. (https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/disease/ergot-of-cereals-and-grasses). Rotation with a non-susceptible crop will lead to loss of viability of the ergot bodies in the field which are the source infective spores. Cultural practices and crop density that minimizes late infertile wheat heads minimizes infection of the sterile florets. Combine settings can be adjusted to minimize ergot bodies retained in the grain.

Leaf spot diseases (Figure 8) can be minimized through practicing Integrated Disease Management (IDM). Because leaf spot disease infectious structures are carried over from season to season in crop debris, these diseases can be minimized through crop rotation.

Other IDM methods include planting disease free seed, tillage, crop rotation, fungicides and choice of varieties with at least a moderately susceptible (MS) level of resistance to leaf spots, and foliar fungicide application. (https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/disease/blackpoint-leaf-spotting-and-smudge-of-wheat). For all leaf diseases including the rusts, it is important to protect the flag leaf, which is a major contributor to grain yield.

The rust diseases, stripe (Figure 9), leaf (Figure 10) and stem (Figure 11), do not overwinter when the winter is harsh, but stripe rust has been found to overwinter in Alberta and Saskatchewan under mild winter conditions. The most economical means of control for these diseases is the use of resistant varieties and a foliar fungicide.

Diseases in pictures

FIGURE 4. *Fusarium head blight (Photo by R. Knox, AAFC).*

FIGURE 5. *Loose smut (Photo by C. Barlow, AAFC).*

FIGURE 6. *Common bunt (Photo by R. Knox, AAFC).*

FIGURE 7. *Ergot (Photo by C. Barlow, AAFC).*

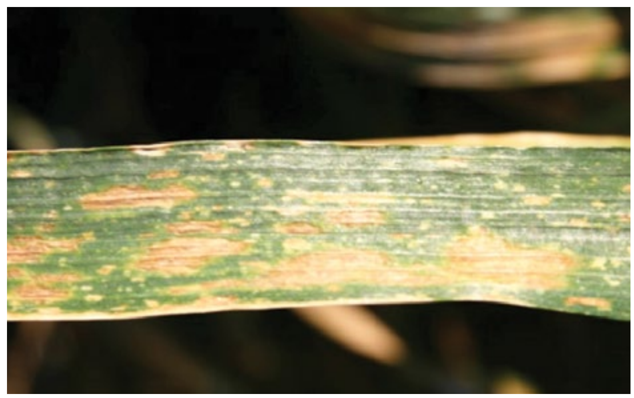

FIGURE 8. *Leaf spot complex (Photo by R. Knox, AAFC).*

FIGURE 9. *Stripe rust (Photo by R. Knox, AAFC).*

FIGURE 10. *Leaf rust (Photo by R. Knox, AAFC).*

FIGURE 11. *Stem rust (Photo by R. Knox, AAFC).*

Web resources

Diseases:

https://www.gov.mb.ca/agriculture/crops/plant-diseases/index.html

https://www.ag.ndsu.edu/ndipm/publications/wheat/documents/pp1552.pdf/view

Managing FHB:

https://www.grainscanada.gc.ca/str-rst/fusarium/fhb-wc-foc-eng.htm

http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/faq12513/$FILE/ARDfhbposterver6.pdf

Fusarium incidence maps:

https://www.grainscanada.gc.ca/str-rst/fusarium/fhb-mc-feccg-en.htm

12. INSECT PEST MANAGEMENT

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Introduction

All crop fields are ecosystems and therefore have a mix of insects, including pests, beneficial and neutral insects. Pest insects can be a major limitation to durum production in the Canadian prairies through both yield loss and reduced quality. However, beneficial insects are a resource and therefore are best to be conserved. Best practices for pest control include a multi-pronged approach that considers economic and ecological costs and benefits of control, otherwise known as Integrated Pest Management (IPM).

IPM includes cultural, biological, mechanical, behavioural and chemical control (see Philip (2015), p. 9-11 for details http://publications.gc.ca/collections/collection_2015/aac-aafc/A59-23-2015-PDF1-eng.pdf. Insecticide often kills both pest and beneficial insects, therefore should be used only when economically warranted.

In general, crop rotation should be used to discourage pest insects. Producers can access local pest prediction maps (http://prairiepestmonitoring.blogspot.ca/) and use resistant durum varieties when pest risk is high or as a general insurance practice. Chemical control may be necessary when economic thresholds are reached, see Philip (2015) for a complete list of thresholds. Making this decision requires regular scouting for pests and beneficial insects. Beneficial insects can be protected by avoiding use of foliar insecticides during active periods, or through agronomic practices such as leaving taller stubble when wheat stem sawfly is a problem. Some beneficial insects that feed on sawfly larvae overwinter in the mid to upper part of stems. Pest history of a field should be considered when determining whether an insecticide seed treatment is necessary (e.g. for wireworm).

In this chapter, we outline the main pest insects of durum wheat on the Canadian prairies in context of IPM, and highlight some of the key beneficial insects that provide value in durum and all prairie crop production systems.

Wheat Stem Sawfly

Wheat stem sawfly (*Cephus cinctus*, Hymenoptera: Cephidae), is a native wasp-like insect that has adapted to use durum wheat and most other cereal crops, except oats, as a host plant. This historical pest is present in the entire Canadian durum production area and has caused hundreds of millions of dollars of grain losses annually in the past decades during outbreaks (Beres et al. 2011).

Sawfly adults (Figure 1A) emerge in the spring and lay eggs in the stems of elongating wheat. Sawfly larvae (1 per stem) feed on pith tissue and move down to the base of the stem to overwinter. There, the larva cuts a "V-shaped" notch in the stem, making it prone to lodging. Sawfly thereby causes losses in two forms: reduction in grain yield and quality from reduced nutrient translocation due to pith damage, and loss of harvestable wheat from "cut" stems. Larvae overwinter in the base of the stem, and pupate in the spring when the new adult sawflies will emerge.

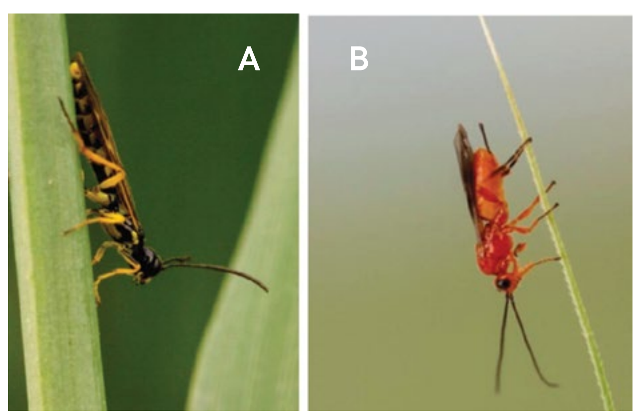

FIGURE 1. *A) Adult wheat stem sawfly, length is 8-13 mm. B) Adult parasitoid Bracon cephi, length is just a few mm (minus antennae). Photos by Shelley Barkley, Alberta Agriculture and Forestry.*

Control methods for wheat stem sawfly may be warranted when 10-15% of last year's field is cut (Philip 2015). However, effective chemical control does not exist for this pest. The most effective management system is a combination of cultural control and biological control. Cultural control consists of crop rotation away from cereals and using resistant (solid-stemmed) varieties (cultivar selection Table 1). Solid-stemmed durum varieties have been available commercially in Canada since 2015. These solid stem durum varieties will minimize damage to durum from wheat stem sawfly. These cultivars have superior stem solidness compared to bread wheats, have no yield drag, and do not require altered sowing densities to achieve solidness (Nilsen et al. 2016). Early swathing in hollow-stem varieties can reduce yield losses due to toppling over of the sawfly notched stems.

Sawfly has two native parasitoid wasps on the Canadian prairies, *Bracon cephi* (Figure 1B) is the main contributor to biocontrol, while *Bracon lissogaster* is rare so far. These tiny beneficial wasps lay their eggs inside wheat stems where the wasp larvae consume and kill nearby sawfly larvae. *Bracon cephi* can effectively control sawfly populations especially in years where the wasp completes two generations (i.e., wetter years which increase the wheat cropping cycle). Dry seasons with early harvests favour sawfly infestations. Parasitoids overwinter higher up in wheat stems than sawfly larvae, and so biocontrol is aided by leaving at least 1/3 of the stem length as stubble on the field (Meers 2005). It is also important to consider the active periods of adult parasitoid flight when spraying foliar insecticide for other pests.

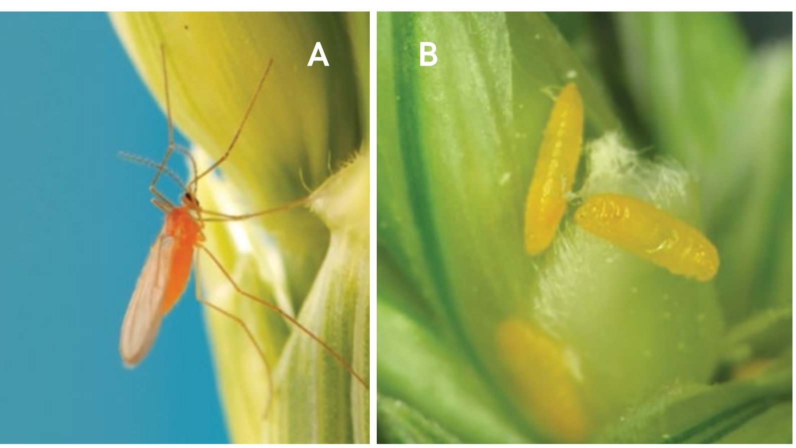

FIGURE 2. *A) An adult wheat midge on a spike of wheat. B) Wheat midge larvae feeding on wheat kernel. Photos by Ian Wise, AAFC-Winnipeg.*

The Alberta government surveys for wheat stem sawfly each year and creates forecast maps that can guide producer decisions to take control measures for sawfly each year. (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm16170)

Wheat Midge

The orange wheat blossom midge (hereafter, wheat midge) *Sitodiplosis mosellana* (Diptera: Cecidomyiidae), is an invasive species that was accidentally introduced into North America from Europe in the early 1800s (Felt 1921). Damaging outbreaks of midge in North American wheat growing regions became common in the 1980s and 1990s causing 70-130 million dollars of crop loss depending upon the year (Doane and Olfert 2008). Assessments of grain samples by the Canadian Grain Commission and the Cereal Research Centre estimated that annual losses to spring wheat in the 2000s in Western Canada reached as high as $300 million, with annual losses averaging $60-70 million for the decade. This pattern indicates the wheat midge is now a persistent and serious pest of spring wheat in Western Canada.

Wheat midge eggs are laid onto the glumes of wheat spikes in early July in Western Canada after the adults (Figure 2A) emerge from pupae in the soil (Doane and Olfert 2008; Mukerji et al. 1988). First instar larvae hatch from eggs within 4-7 days, crawl to developing kernels (Figure 2B) and feed for three weeks while passing through a second larval instar. After three weeks, the third instar larvae go dormant within the skin of their previous on durum heads. Moisture, such as a heavy dew or rain activates them to shed their second instar skin and drop to the soil where they quickly burrow beneath ground and form an overwintering cocoon mostly in the upper 3 cm (Doane et al. 2000). Sufficient rainfall and warm soil spurs their development into pupae which emerge as adult midges three to four weeks post-rain event. Drier conditions in the spring can lead to a long period of adult emergence and damage to kernels of secondary and tertiary tillers.

Monitoring for wheat midge

Soil moisture is the initial trigger for wheat midge development from overwintering larva to pupa and an accumulated rainfall of 25mm through May is necessary to start midge development along with soil temperature greater than 5°C (Elliott et al. 2009).

Sufficient soil moisture at this time allows the midge to emerge in synchrony with the durum spike to lay eggs on the most susceptible growth stages which are from boot splitting to just before anthesis (51-59 Zadoks, the advanced heading stage). Durum susceptibility to midge decreases drastically by mid-anthesis and late anthesis (Zadok's scale 65-69) (Elliott and Mann 1996). In Western Canada, late June but mostly July is the month to begin scouting for wheat midge in your fields because the most susceptible growth stage of durum wheat is emergence of primary wheat heads from the boot (Elliott and Mann 1996). Yellow sticky cards, placed at canopy height in your fields and checked for adult midge each morning, can alert you to the emergence and action of wheat midge in your field. Pheromone traps that mimic the scent of female midges to attract male midges are also useful to determine midge emergence and trap catches can be related to damage later in the season (Bruce et al. 2007; Gries et al. 2000). When adult midges are detected, more intense scouting at dusk becomes necessary. There are two economic thresholds (ET) to keep in mind when scouting: 1 adult midge per five heads of durum is the ET for yield loss prevention (15% yield loss) and 1 adult midge per eight to ten heads is the ET for prevention of grade loss (Guide to Crop Protection https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/crop-guides-and-publications/guide-to-crop-protection). An insecticide needs to be applied without delay when the crop is susceptible and the ET has been reached. However, midge tolerant varieties do not require application of an insecticide.

Crop resistance to wheat midge

Provincial ministries in Alberta and Saskatchewan survey the population of overwintering wheat midge larvae in the fall and prepare a map of the risk of wheat midge across the western Canadian growing region. (Alberta: http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/prm16530 and to Saskatchewan: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/insects/wheat-midge/wheat-midge-map) The map is posted on their respective government websites prior to the next growing season so that growers can make informed planting and spraying decisions based on their own wheat midge risk.

A gene found in winter wheat, that conferred resistance to feeding by first instar wheat midge nymphs, named the *Sm1* gene (Sm stands for *Sitodiplosis mosella* which is the latin name for orange wheat blossom midge) has been conventionally bred into spring wheat and durum. Wheat midge tolerant durum must be managed carefully to prevent the wheat midge from developing resistance to the *Sm1* gene. The Midge Tolerant Wheat Stewardship (www.midgetolerantwheat.ca) has a stewardship agreement in place for anyone wishing to grow midge tolerant wheat. The main purpose of the agreement is protect the *Sm1* gene. The midge tolerant certified seed has a mix of 90% of the *Sm1* variety and 10% of a susceptible durum variety that acts as a refuge. The refuge plants are used to minimize the likelihood midge populations will develop resistance to the *Sm1* gene by allowing susceptible midge to survive to breed with any mutant midge that might have developed resistance. To maintain the approximate ratio of 90:10, the stewardship agreement limits the use of farm-saved seed to only one generation past certified seed.

By not spraying an insecticide, producers preserve the population of the wheat midge parasitoid, *Macroglenes penetrans* (Hymenoptera: Pteromalidae). Varieties of durum that carry this gene are indicated with a VB following the variety name and include: AAC Marchwell VB with a refuge of AAC Raymore, CDC Carbide VB with a refuge of CDC Vivid, and AAC Succeed VB with the refuge CDC Alloy.

Varieties with the *Sm1* gene produce p-coumaric and ferulic acids during early seed development whereas non-carrying *Sm1* varieties initiate production of these compounds at a later stage. The midge larvae are unable to grow in the presence of these compounds. Therefore, *Sm1* is considered to have an antibiotic response. In ripe seeds, resistant and susceptible wheats have similar levels of phenolic acids. However, the activation response of *Sm1* in durum varieties to feeding by the midge seems to be slower than in some varieties of spring wheat. Differences in this activation response have been found in spring wheat and its cause is currently being investigated. Durum selections also are being tested to assess feeding responses in the hope that more tolerant varieties will be released. Midge damaged kernels can remain with undamaged kernels at harvest and may result in grade reduction so monitoring for adult midge with a plan to treat with insecticides is still necessary under high midge pressure.

Cereal Aphids

The English grain aphid (EGA), *Sitobion avenae* (Figure 3) is one of the most damaging aphids in cereal crops with its habit of feeding on durum heads during seed filling which can negatively affect yield. Wheat yield can be reduced by 20-30% in aphid outbreaks (Kolbe and Linke 1974) with yield reduction of 10% with 30 aphids/head to 30% with 150 aphids/head (Kolbe and Linke 1974). The economic threshold (ET) of EGA on cereals most often used in Western Canada is 12-15 aphids/tiller (Gavloski and Olfert 2011; Harper 1973). Cereal aphid populations can quickly exceed this threshold if left unchecked (Kieckhefer and Gellner 1992; Kieckhefer and Kantack 1980) and can reduce yield by 35-40% at this level of infestation, depending upon the crop stage (Kieckhefer and Gellner 1992).

FIGURE 3. *Oat-birdcherry aphid (bottom) with nymphs and English grain aphid (top). Photo by Tyler Wist, AAFC-Saskatoon.*

Aphid management

Chemical sprays may be required if the aphid population is predicted to exceed the ET. However, if natural enemies such as lady beetles and parasitic wasps are present they can suppress aphid populations and prevent the ET from being exceeded. With a sufficient number of natural enemies, chemical control of aphid populations may not be necessary. Three other aphid species can also attack durum and two of these, the greenbug, *Schizaphis graminum* and the Oat-birdcherry aphid, *Rhopalosiphum padi* (Figure 3), have been present in fields recently, but in lower numbers than EGA (Wist, unpublished data). A smartphone (or tablet) app called "Cereal Aphid Manager" created by Agriculture and Agri-Food Canada scientists is available as a free download from the Apple and Android stores. This app is for scouting aphids in cereal fields and the wheat selection can be used for durum. The app allows for numbers of aphids per head to be recorded as well as the number of natural enemies observed. A recommendation is made after sufficient sampling that takes into account the suppressing action of the natural enemies present on the aphid population in your field. Durum varieties do not seem to be particularly resistant to aphid feeding (Migui and Lamb 2003) except that awned heads are more resistant than awnless (Acreman and Dixon 1986).

PLEASE SCAN THIS QR CODE TO LINK TO THE CEREAL APHID MANAGER APP IN YOUR RESPECTIVE ONLINE STORES.

Wireworms

In Canada, the term "wireworm" refers to the larval stage of a group of approximately 30 pest beetle species (Coleoptera: Elateridae) (Vernon and van Herk 2013). The adult stage, called click beetles, lays eggs but does not harm crops directly. However, the larval stage is a problematic soil-dwelling pest as it typically spends 1-5 years, or even up to 11 years in the soil (van Herk and Vernon 2014), where it eats crop seeds, seedlings, and roots. Wireworm feeding thins crops and reduces yield. Wireworms will consume most crops, and all cereals, including durum wheat (Adhikari and Reddy 2017), are favoured hosts. Wireworms are generally yellow in colour with hard bodies, and often have a "keyhole-shaped" notch on their back end. There are 3 prominent wireworm species on the Canadian prairies, all of which are native, *Selatosomus aeripennis destructor, Limonius californicus, and Hypnoidus bicolor* (Figure 4).

From the 1940s to the mid 2000's wireworm populations in Canada were controlled with organochlorine pesticides such as lindane (Vernon and van Herk 2013). However, since the de-registration of those pesticides in 2004, chemical control has been inadequate. The best currently available options for maintaining production on heavily infested land are neonicotinoid seed treatments. However, these treatments do not kill wireworms. They provide in-season crop protection by temporarily stunning wireworms (Vernon et al. 2009), but the wireworms will remain alive in the soil to attack next year's crop. Wireworms are a patchy pest and are difficult to monitor (Vernon and van Herk 2013). Consider the wireworm history of a field when deciding if insecticide seed treatments are necessary. Wireworms can be sampled prior to seeding using home-made CO_2-producing underground bait traps. A cup of soaked cereal seed in a mesh bag left underground for 1 week will attract wireworms. However, economic thresholds are currently unknown, and would vary with the species present. Research is ongoing across Canada to develop new IPM methods for wireworm control, including potential trapping of click beetles to reduce eggs laid.

Cutworms

The three main cutworm pests that consume cereal crops in the prairies are Redbacked cutworm (*Euxoa ochrogaster*, Pale western cutworm (*Agrotis orthogonia*), and Army cutworm (*Euxoa auxiliaris*) (Gavloski and Catton 2017). See the most up-to-date version of the Western Committee on Crop Protection guidelines for cereal grains for latest economic thresholds and chemical control options (Gavloski and Catton 2017, http://www.westernforum.org/wccp%20guidelines.html). Floate (2017) provides a detailed breakdown of species identification, behaviours, life cycles, and economic thresholds. Check local crop protection guides for chemical control options.

Grasshoppers

Grasshoppers are cyclical pests of cereals, with numbers depending on weather patterns. See Johnson (2008) for a detailed breakdown of species identification, behaviours, life cycles, economic thresholds, and controls. (https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/rsv13511/$FILE/Mar11_2008_grasshopper_book_DJ.pdf) See the most up-to-date version of the Western Committee on Crop Protection guidelines for cereal grains for latest economic thresholds and chemical control options (Gavloski and Catton 2017). (http://www.westernforum.org/WCCP%20Guidelines.html)

***FIGURE 4.** The three most common pest species of wireworm on the prairies in their larval and adult (click beetle) forms. From left to right, Selatosomus aeripennis destructor, Limonius californicus, and Hypnoidus bicolor. Note the different sizes and colours. Photo by David Shack, AAFC-Lethbridge.*

Hessian Fly

The Hessian fly, *Mayetiola destructor*, is the most serious insect pest of winter wheat in North America. Durum wheat in Western Canada is susceptible to stem breakage caused by larval feeding but seeding before June will largely prevent most feeding injury.

Cereal Leaf Beetle

Cereal leaf beetle (*Oulema melanopus*, Coleoptera: Chrysomelidae) is an invasive defoliating crop pest from Eurasia, first verified in Alberta in 2005 (Canadian Food Inspection Agency 2013). The beetle now occurs in all three Canadian Prairie Provinces (Dosdall et al. 2011). Adult cereal leaf beetles are iridescent green and red (Fig. 5), and larvae have a slug-like appearance as they carry their own feces on their backs. Both adults and larvae live and feed on foliage, leaving distinctive longitudinal lines of damage on leaves of multiple cereal crops, including durum (Rouag et al. 2012). In the only study of cereal leaf beetle on durum to our knowledge, researchers in North Africa found that larval feeding caused 3-23% yield loss with <10% defoliation of the flag leaf, and 29-86% yield loss with >40% defoliation on the flag leaf (Rouag et al. 2012). No economic thresholds have been determined specifically for durum, however, thresholds for foliar insecticide application in winter wheat are estimated in the USA to be 0.4-1.0 larvae per flag leaf (Buntin et al. 2004, Webster and Smith 1983).

Cereal leaf beetle rarely reaches economic threshold levels on the prairies. One reason for this is the parasitoid biocontrol wasp *Tetrastichus julis* (Hymenoptera: Eulophidae). This tiny wasp lays its eggs inside cereal leaf beetle larvae, where the immature wasps kill the pest by eating it from the inside out. *T. julis* is considered the primary management tool for cereal leaf beetle across North America (Kher et al. 2013). It has been re-distributed on the prairies to new cereal leaf beetle infestations and is considered a successful biocontrol agent for this pest on the prairies. Therefore, spraying insecticide for cereal leaf beetle below economic thresholds is not recommended as it kills the beneficial *T. julis* wasps as well.

Beneficials

Cereal crop fields contain two main types of beneficial arthropods: specialists and generalists. Specialists specialize on one pest insect and include biocontrol insects such as the tiny wasps that attack wheat stem sawfly (*Bracon cephi*), wheat midge (*Macroglenes penetrans*), aphids (*Aphidius* spp.), and cereal leaf beetle (*Tetrastichus julis*) in a very targeted way.

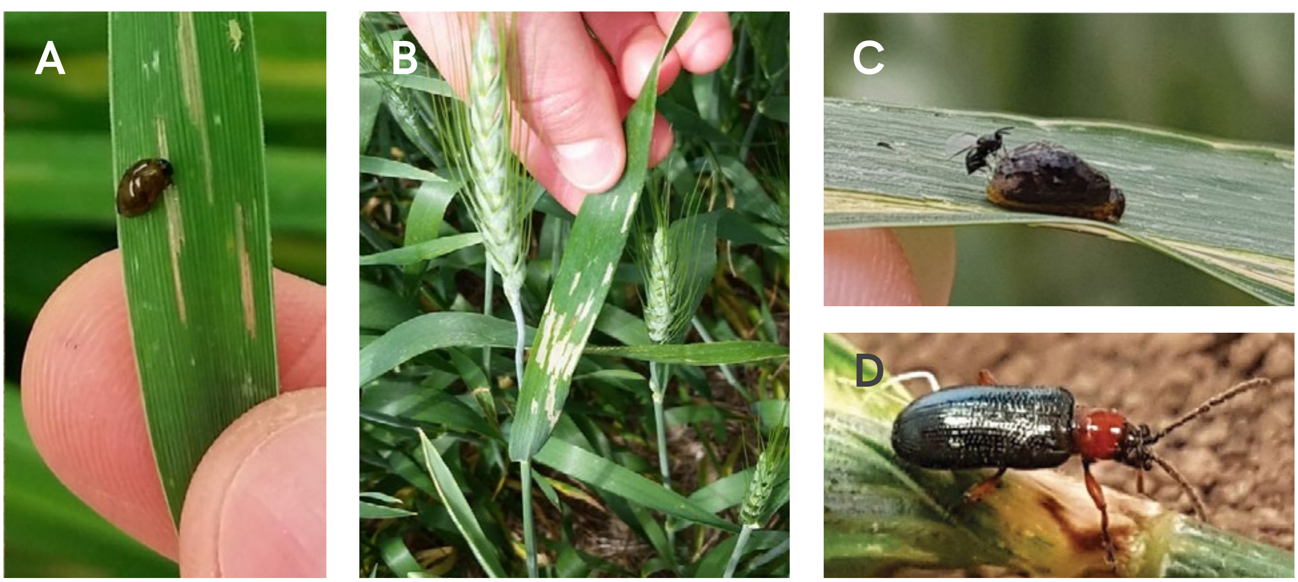

FIGURE 5. *A) Larval cereal leaf beetle and distinctive linear feeding, B) Flag leaf damage on spring wheat, C) T. julis wasp parasitizing a cereal leaf beetle larva, D) Adult cereal leaf beetle. Photos A & B by Haley Catton, AAFC-Lethbridge; Photo C by E. Lemke, AAFC-Lethbridge; Photo D by D. Shack, AAFC-Lethbridge.*

Generalists are beneficial insects and arthropods that consume a wide variety of pests. These could include the hundreds of prairie species of ground (carabid) beetles, lady beetles, damsel bugs, spiders, and other residents of crop fields (described nicely with photos in Philip (2015)). These beneficials are valuable, they make up an "unpaid army" by consuming weed seeds, and insect pest eggs, larvae, pupae and adults. Disrupting beneficial populations through unnecessary pesticide use may result in an economic loss, pest re-bounds and population booms of secondary insect pests. Plant diversity, specifically flowering plants around a crop field can add value. For example, parasitoid wasps feed on flower nectar and so can benefit from flowering weeds around fields. More details about beneficials are available from the Field Heroes campaign (www.fieldheroes.ca).

Web Resources

AAFC's Cutworm pests on the Canadian Prairies: Identification and management field guide. http://publications.gc.ca/collections/collection_2017/aac-aafc/A59-42-2017-eng.pdf

AAFC's Field crop and forage pests and their natural enemies in Western Canada: Identification and management field guide. Agriculture and Agri-Food Canada. http://publications.gc.ca/collections/collection_2015/aac-aafc/A59-23-2015-PDF1-eng.pdf

Alberta Insect Pest Monitoring Network http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/All/prm13779

Field Heroes (beneficial insect campaign): http://www.fieldheroes.ca/

Midge Tolerant Wheat: http://www.midgetolerantwheat.ca/

Prairie Pest Monitoring Network Blog (PPMN): http://prairiepestmonitoring.blogspot.ca/

Western Committee on Crop Pests Guide to Integrated Control of Insect Pests of Crops http://www.westernforum.org/wccp%20guidelines.html

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13. HARVESTING TO MINIMIZE LOSSES

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Photo credit: SOUTH WEST TERMINALS

Introduction

While good agronomic practices can maximize durum yields, proper harvest management will deliver those yields in the current year and set up best management practices for year two. Seed yield and quality losses can be minimized with proper harvesting and handling techniques. The durum wheat crop fits a multi crop rotation system. Efficiencies are gained when the same machines can be used for multiple crop types and can be adjusted to minimize the harvest factors that result in loss of grain market value.

Harvest may start in August but continues into September and October when the temperatures become cooler, days are shorter, humidity is higher, and snowfall happens occasionally. In high latitudes of the Northern Hemisphere, weather conditions deteriorate as the harvest progresses. Consequently, there is urgency to complete harvest as soon as possible. Grain grade of durum is negatively affected by wet conditions at harvest. (https://www.grainscanada.gc.ca/oggg-gocg/ggg-gcg-eng.htm) For example, heavy dews and light rain can cause bleaching of the kernels so that they lose hard vitreous appearance. The moist conditions might initiate germination of the kernels. The impact of the loss of the amber appearance and having a duller chalky appearance and even 7% sprouted kernels would down grade the grain from a No. 1 to a No. 3, which results in a loss of about 10% of its value. Scaling this up to a 3000 acre farm with half in durum at 45 bus/ac crop (about 3 t/ha), the loss in value would be about $55,000.

Furthermore, if the grain is tough or damp it must be dried. If the straw and chaff are not dry, the combine and straw chopper consume more energy to separate the grain from the straw and chaff and to chop and spread the straw. Energy consumption increases to harvest under damp conditions.

The expression one day lost in the spring requires two days in the fall illustrates the pressures to complete the crop cycle rapidly. Components of this are achieved by early seeding, high seeding rates, uniform plant canopy, and weed control.

A combine harvester is a machine that combines the tasks of cutting (harvesting), threshing, and separating (cleaning) grain from chaff. (http://www.newworldencyclopedia.org/p/index.php?title=Combine_harvester&oldid=1003661) Details will not be provided but more information can be found in the references provided and details are available from equipment manufacturers.

The productivity of combine harvesters are continually being improved through new technologies. Refinements such as header height control, flexible headers, threshing and separating modifications, automated threshing and cleaning adjustments, GPS facilitated auto-steer, uniform spreading of straw and chaff, and yield mapping have increased machine capacity, increased operator efficiency, reduced grain damage, and improved productivity of the overall cropping system. This section will describe some of these new technologies available with modern combine harvesters and how it fits into good crop and soil management practices.

Swathing vs direct combining of durum

Durum wheat achieves maximum dry weight when the kernels reach 30% to 35% moisture on a wet weight basis. (Zadoks stage 86 to 89). (Growth Stages and to https://www.usask.ca/agriculture/plantsci/winter_cereals/winter-wheat-production-manual/chapter-23.php) At this stage the kernels have lost almost all the green color except perhaps in the crease. The kernel can be squeezed and only a glistening of moisture will appear at the end of the kernel. Grain is not safe for storage until it is below 14.5% moisture (section 14). However, producers often start harvest at about 18% moisture and then dry the grain to safe storage moisture.

Traditionally, the start of cutting durum wheat was about 30 to 35% moisture (Zadoks stage 87 to 89) and laid into a windrow directly onto the cut stubble. As equipment has increased in size the windrow has become very large and the drying down of the kernels in the lower portions of the swath is slow compared to the upper portion of the swath. Consequently, a standing crop will dry down as fast or faster than a bulky thick windrow.

The old varieties were taller and weaker strawed compared with the new varieties. These taller weaker varieties had to be swathed before they toppled over. Many of the new varieties are shorter and stronger strawed compared with the older varieties. Consequently, the shorter and stronger varieties fit better into a straight combining system which eliminates the operation of swathing. Solid stem varieties reduce infestation by the wheat stem sawfly and thereby reduce the incidence of stems cut by sawfly and toppling over. Harvesting these toppled over stems necessitated leaving a very short stubble.

Direct combining saves labor, energy, and when coupled with drying systems can speed up the harvest.

Swathing or windrowing may not provide Canadian farmers with a means of significantly speeding up grain drying when crop maturity is uniform. However, swathing does have a place in dealing with uneven maturity, green weeds, and secondary crop growth that results from uneven plant emergence or secondary emergence of tillers.

Stubble height

Harvesting should also be viewed as the first step to address soil erosion and moisture conservation. To increase grain yields, producers in the semiarid prairies who direct-seed durum wheat are advised to seed into stubble left standing as tall as practical (at least 12 inches (30 cm)). Durum is often grown in rotation with a pulse crop that has a short stature and crop residue which decomposes rapidly and reduces the snow trapping potential. Canola and mustard have crop residue height and decomposition rate intermediate to durum and pulses. Yield improvements from snow management with cereal stubble usually exceeded the small costs of implementing snow trapping practices.

Header

A header is a tool used to cut the grain heads from the durum wheat stalk. There are two basic header types, draper headers and stripper headers. Draper headers cut or swath the plant stem, and the cut stem and head topple onto a moving drape towards the auger conveyor which moves the cut heads to the threshing device. There are various designs of headers currently up to 50ft (15m). Some headers are designed to have a flexible table and knife, reversible machine drive, pick up fingers, and air suspension.

The stripper header does not cut the wheat stalk but rather engages wheat heads with plastic-backed stainless-steel combs attached to a transverse rotor. The rotor rotates in the opposite direction of the combine wheels, so the heads are combed with a forward and upward motion. Most of the kernels are threshed from the head and enter the combine as loose grain.

Depending on crop conditions, part of the grain may enter as unthreshed heads and head fragments. Because a stripper header functions better when the chaff, grain and straw are dry, and the humidity is moderate to low, stripper headers are not common in Canada. Harvest may start in August but continues into September and October when the temperatures are cool, days are short, humidity is high, and snowfall is just around the corner.

However, some large producers in the southwest will harvest in alternating passes of a draper header attached to the combine and a stripper header combine. They use a strong strawed durum variety with an upright plant stature. The draper header is adjusted to leave tall stubble but the stripper header leaves a very tall stubble. In the following spring, these producers plant with a no-till direct planter traveling perpendicular to the direction of the travel of the combine so as to minimize "hair pinning" of the crop residue and facilitate the passage of residue between the rows of planter shanks. While others, who don't use a stripper header, but practice snow trapping will travel parallel to the previous stubble using technology such as Real-Time Kinematic (RTK) GPS technology (Real-Time Kinematic (RTK): https://www.novatel.com/an-introduction-to-gnss/chapter-5-resolving-errors/real-time-kinematic-rtk/)

Threshing mechanism

There are two basic types of combines "conventional cylinder" and "rotary". Conventional cylinder combines use a cylinder-concave threshing mechanism, with the cylinder-concave perpendicular to the direction of combine travel. Separation of the grain from the chaff and straw is based on cylinder speed, gap setting between the cylinder and concave, followed by agitation in "walkers", and wind.

The rotary combine uses a rotating, threshing, separating mechanism with its axis parallel to the direction of combine travel. Grain and straw and chaff move in a helical, spiraling type path, through the threshing section and then separation section using wind and sieves.

ADJUSTMENT OF THE COMBINE MOVING PARTS SHOULD RESULT IN MINIMUM GRAIN LOSS AND DAMAGE AT ALL STEPS: CUTTING, THRESHING, SEPARATING. THE FOLLOWING ARE GRAIN GRADING FACTORS, LISTED ALPHABETICALLY AND NOT BY IMPORTANCE, THAT ARE DIRECTLY AFFECTED BY THE HARVESTING PRACTICES AND MACHINE OPERATIONS:

- Degermed kernels (DGM)
- Green (GR) and Grass green kernels (GRASS GR)
- Matter other than cereal grains (MOTCG)
- Natural stain
- Ruptured kernels (RUP)
- Shrunken (SHR) and Broken (BKN)
- Stones (STNS)
- Other cereal grain (OCG)
- Wheats of other classes or varieties (WOOC)

See the CGC grain grading guide: https://www.grainscanada.gc.ca/oggg-gocg/ggg-gcg-eng.htm

See the CGC grain grade guide for grades of Canadian Western Amber durum within: https://www.grainscanada.gc.ca/oggg-gocg/04-wheat-2017-eng.pdf

BEAUTIFUL CANADIAN DURUM GRAIN SAMPLE

Photo credit: R.M. DEPAUW

Straw chopping and spreading

Minimum tillage or zero tillage starts with managing straw and chaff. Critical is the chopping of the straw into small enough lengths and spreading it uniformly over a width, comparable to the header width, to minimize "hair pinning" or plugging the planting equipment during the direct seeding step the following spring. Excess straw and chaff in the chopper tail can negatively affect soil/seed contact and seedling emergence. In the event of excess straw and chaff, it can be managed with a "heavy harrow" or "vertical tillage" as a last resort. Another advantage of shorter strong strawed varieties is their contribution to the ease of managing the residue to fit reduced tillage and direct planting operations.

Flexibility of zero tillage and reduced tillage systems ensure long term success, environmental conservation and sustainability. (http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-management/flexibility-of-no-till-and-reduced-till-systems-ensures-success-in-the-long-term/?id=1219778199286)

Combine sensors and control systems

Today's combines are complex and very sophisticated with a number of electronic monitoring and guidance systems. Although general combine design and processes have changed little, there have been many recent advances in sensors and control systems. Steering and speed control systems are relatively common on the new makes and models. Yield monitors, and moisture and protein sensors to gather data regarding crop production are also available. There are a range of automated header height control systems. Automatic steering systems are the norm coupled with speed control and load control. Grain yield monitors collect data which can be used to generate productivity maps. The data collected from these sensors can seamlessly be linked into the Big Data of Smart Farming platforms. The industry will continue to make advances in an attempt to automate repetitive harvest tasks.

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Web Resources

CGC grain grading guide: https://www.grainscanada.gc.ca/oggg-gocg/ggg-gcg-eng.htm

See the CGC grain grade guide for grades of Canadian Western Amber durum: https://www.grainscanada.gc.ca/oggg-gocg/04-wheat-2017-eng.pdf

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14. STORAGE OF DURUM WHEAT TO AVOID QUALITY LOSS

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Introduction

Countries have strict regulations for residues in food and feed. Proper storage will help prevent downgrading of the grain due to the formation of harmful mycotoxins, cross contamination or chemical residues. Like all cereal crops durum must be stored dry (below 14.5% moisture content, wet weight basis) and cool (below 20°C as quickly as possible after harvest). A comparison of tough and damp cereals, oilseed and pulses from the Canadian Grain Commission is useful.

CROP	MOISTURE CONTENT (WET WEIGHT BASIS) TOUGH (%)	DAMP (%)
Wheat	14.6-17.0	>17.0
Durum	14.6-17.0	>17.0
Buckwheat	16.1-18.0	>18.0
Oats	13.6-17.0	>17.0
Barley	14.9-17.0	>17.0
Flaxseed	10.1-13.5	>13.5
Canola (Rapeseed)	10.1-12.5	>12.5
Mustard seed	9.6-12.5	>12.5
Rye	14.1-17.0	>17.0
Peas	16.1-18.0	>18.0
Corn	15.6-17.5	17.6-21.0
Soybean	14.1-16.0	16.1-18.0
Sunflower	9.6-13.5	13.6-17.0

Good Storage Practices that Apply to Durum Wheat:

Recommended by Agriculture and Agri-Food Canada in co-operation with the Canadian Grain Commission and the Keep it Clean! campaign (https://keepingitclean.ca/)

- Prevent losses from insects, mites and moulds by storing grain, oilseeds and pulse crops properly; preventing infestations is easier, safer and less expensive than controlling them.
- Prepare the bin before storing the new crop: sweep or vacuum the floor and walls; burn or bury sweepings that contain spoiled or infested grain; seal cracks to keep out rain, snow and flying insects; and spray the walls and floors with a recommended contact insecticide.
- Install an aeration system to reduce grain temperatures and to reduce moisture migration.
- Dry tough or damp crops soon after harvest because they are more likely to become mouldy or infested with insects and mites than dry (straight-grade) crops: then cool after drying. Moulds will not develop in dry grain, insects cannot multiply below 20°C.
- Examine stored crops every two weeks for signs of heating or infestation; check either temperatures or carbon dioxide levels; and check insect activity by using traps, or probe and sift grain samples.
- Heated and mouldy crops should be dried. If the heated grain cannot be dried immediately, the rate of deterioration can be reduced by cooling the grain by aeration or moving and mixing the spoiling grain to break up hot spots.
- Insect infestations can be controlled or eliminated by cooling the grain by aeration or mixing it with colder grain. To eliminate insects grain should be cooled to -20°C for one week or -10°C for eight weeks.
- Check the headspace of granaries during January to March and remove any snow before it melts.
- Observe safety precautions when applying insecticides; only persons licenced for fumigation application should apply fumigants.

For further information on managing stored grain to maintain quality and manage insect infestations go to the Canadian Grain Commission web site. (http://www.grainscanada.gc.ca/storage-entrepose/mqsgm-mgqge-eng.htm)

Safe Storage Guidelines: Producers can use the following chart to prevent spoilage of stored durum and hard red spring wheat

How to use the chart:

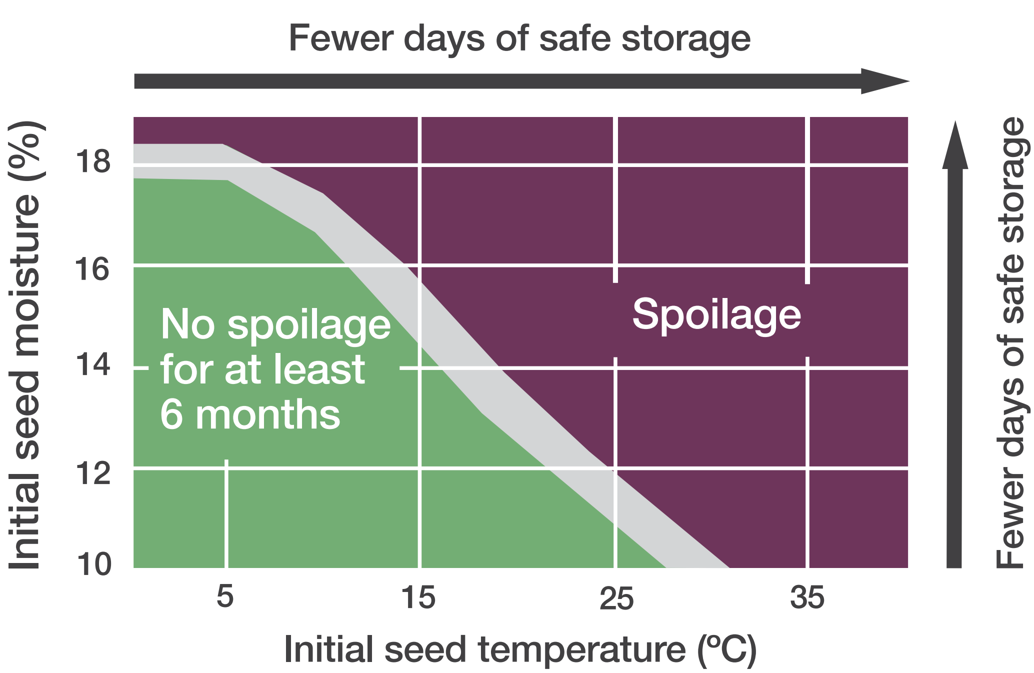
- Measure the moisture content and temperature of your crop as it goes into storage.
- Plot the initial moisture content and initial temperature on the chart. If the result falls into the no spoilage area, then your crop should store safely for up to 6 months. If it falls into the spoilage zone, seed deterioration will begin to take place.
- Cool or dry the crop in storage until the temperature or moisture content put it into the no spoilage zone.
- The centre zone cuts off a 1% safety margin although spoilage may occur under these conditions.
- Be aware that the moisture content and temperature of a bulk may change during storage due to convection currents leading to localized spoilage. Monitor the top-centre of the bulk regularly through out storage or use aeration.

Contamination of Durum Wheat with Ochratoxin A During Storage

Ochratoxin A is a fungal metabolite produced by two very common fungi in Western Canadian storage. *Penicillium verucosum* and *Aspergillus ochraceous* produce this toxin in wet wheat, notably durum (Abramson et al. 1990). Other mycotoxins produced by Fusarium species can be present in Fusarium damaged kernels. These mycotoxins can increase if stored in warm humid conditions. Drying and storing durum is important to reduce build up of mycotoxins. When snow or rain get into a granary, pockets of grain get wet and moulds develop, creating a hot spot. Very high levels of toxin can be present on a few kilograms of seed but when mixed at unload result in overall levels above 5 parts per billion, the limit for export to Europe.

References

Abramson, D., Mills, J.T., Sinha, R.N. 1990. Mycotoxin production in durum wheat stored at 15% or higher moisture content. Food Additives and Contaminants 7:617 - 627



Source: Canadian Grain Commission website Reproduced with the permission of Dr. Noel White, Agriculture and Agri-Food Canada, Cereal Research Centre, Winnipeg.

15. MARKETING TO ACHIEVE VIABILITY

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Introduction

Durum, a class of wheat which is mainly milled into semolina for the production of pasta, has a much smaller market than bread wheat. Due to the small size of the durum market, there is no commodity futures market available for indicating price. The only indicator is the last reported durum export sale and these sales occur infrequently. This lack of global price information leads to durum prices fluctuating more than other wheats.

Where can I find a price for my durum?

At the time of writing, the only source of durum wheat pricing information available to the Canadian farmer is local buyers. These are elevator grain buyers who will export internationally, domestic users such as pasta mills, grain brokers who will resell, and feed mills who produce animal feed. Each of these buyers will employ an individual under the title of "grain buyer" who can offer you a daily price in either bushels or tons. Contact a grain buyer near your farm and they will provide a specific price for your durum.

There are also independent online sources to obtain a price for durum wheat. The Price and Data Quote system (www.pdqinfo.ca) is an independent provider of daily average elevator price for nine different regions in Western Canada. The governments of Alberta, Saskatchewan, and Manitoba also release weekly market price updates.

The releases are given the following titles which can be searched for online:

- ALBERTA – Weekly Crop Market Review http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd6248
- SASKATCHEWAN – http://www.saskwheatcommission.com/wheat-market-outlook/
- *AGR Market Trends* http://applications.saskatchewan.ca/agrmarkettrends
- MANITOBA – Grains and Oilseeds Market Price https://www.gov.mb.ca/agriculture/market-prices-and-statistics/crop-statistics/grains-oilseeds-market-prices-current-year.html

How can I sell my durum?

Grain elevators, domestic users, and grain brokers all have an interest in buying bulk durum that is suitable for human consumption. Their preference is for clean, dry, disease free kernels. Elevators and brokers resell the durum to buyers who specify maximum limits on the amount of foreign material other than wheat kernels that is acceptable for their purchase. These buyers also specify limits on kernel moisture to ensure that the wheat does not spoil during transport. High moisture conditions may favour fungal growth which may result in mycotoxin accumulation and grain quality degradation. In order to meet these standards, elevators may be required to clean and dry the wheat they purchase. A farm that delivers clean and dry wheat to the elevator, will receive fewer discounts.

Feed mills generally purchase durum in smaller amounts than grain elevators but are more interested in grain that is not suitable for human consumption. Feed mills are also interested in having clean, dry, disease free kernels. However, as the products of the feed mill are going into livestock, the feed mill tends to be less selective than the elevator. Should your local elevator be unwilling to purchase your durum, or offers a price that you consider unfair, you should check with your nearest feed mill.

Whoever you sell your durum to, they will require you to sign a contract. This contract will specify a price that the buyer will pay you for the durum, a date for you to deliver the durum to the buyer, and will ask you to guarantee that the durum you deliver will be better than the limits of cleanliness, moisture, and disease that they will specify. These contracts may be referred to as a "future delivery" or "deferred delivery" contract.

Buyers will look for producers to enter into future delivery contracts up to 18 months before the delivery date. These contracts are used by buyers to ensure that they will have the durum wheat when they need it. For the producer who is selling, these contacts can be used to ensure that they will have a steady flow of cash entering the farm over the next year. When the durum price rises to a profitable level, many farmers will enter into these contracts with buyers.

Delivery delays

While contracting grain in advance is a farmer's best option for ensuring consistent delivery and cash flow throughout the crop year, there still exist risks from disruptions outside the farmers' control. The process of transporting grain from the Canadian prairie to international destinations involves multiple participants. Delays from any of these participants can ripple back to the farm, resulting in producers holding contracts they are unable to deliver on.

Infrastructure delays

Delays on delivery tend to occur when there is a failure somewhere in the infrastructure required to transport grain. For example, there may be a mechanical failure within the grain elevator. Delays can also occur due to breakdowns of regional infrastructure. Rural roads can be susceptible to floods from heavy rains or sudden melts in the winter. Should the loss of these roads prevent a producer from delivering to the elevator, the elevator may fill with the desired commodity from other sources to ensure their ability to fill an arriving train on time. This can lead to the producers who missed the delivery facing a delay of several weeks until a call is made for the commodity again.

Breakdowns in the rail system can also delay producer delivery. Railways are limited in the amount of service they can provide by the number of engines and crews they have available, and cold weather can further reduce service by impacting break systems, limiting the weight a train can safely carry. Rail breakdown, poor weather, and unexpected demand for rail are all scenarios that could result in trains not being delivered to an elevator at the expected time. As the elevator would have filled expecting a train, the elevator is full until a train arrives and cannot accept further deliveries. This will delay all deliveries until the elevator can empty.The majority of international grain export involves the loading of tens of thousands of tons of grain onto a boat. Several trains of grain are sent to a large storage facility on the edge of the water in port facilities. These storage facilities are known as terminals. Designed to be larger versions of country elevators, terminals suffer the same wear and potential for breakdowns, which can cause delays back through the entire value chain by preventing rail delivery.

HOPPER CARS BEING LOADED AT AN INLAND TERMINAL

Photo credit: SOUTH WEST TERMINALS

Although rare, ships can also arrive late for delivery. As the terminal has filled expecting the boat, the terminal is limited in the ability to unload any other trains. This also can cause delays back through the entire value chain by preventing rail delivery.

Trade wars and tariffs

International buyers purchase grain several months in advance, which creates some uncertainty in the sale. Between signing a contract for purchase and receiving delivery, an international buyer may end up unable or unwilling to honor their contract. Reasons may include the ability to purchase similar grain for a lower price from another destination, or that the buyer has entered bankruptcy. Given that grain shippers have little recourse in these situations, they may delay the delivery of this grain until a new buyer can be arranged. International disputes between governments can disrupt trade if a country enacts tariffs on commodities, increasing the cost of purchasing. If these tariffs are implemented after an agreement is made with an international buyer but before delivery, there is a risk the buyer may no longer honor the purchase agreement. Again, the grain shipper may delay the delivery of grain until a new buyer can be arranged.

What determines the price of my durum?

Most buyers of durum in Canada are planning to resell it internationally. The price of durum wheat exported from Canada is dependent on the annual global supply and quality. If global production has low yield and/or low quality, the demand for Canadian durum will be strong and prices will be high. There are three major production areas that determine the price for Canadian durum wheat: North Africa, Europe, and North America.

In North Africa, the countries of Morocco, Tunisia, and Algeria are durum producing countries which use it to make couscous and bread. The local demand for durum is greater than the local production. This results in a demand for Canadian durum. The amount that this area demands depends on the local yields, which results in markets watching the North African crop closely.

Europe is also a major producer of durum crops, and again their local demand for durum is greater than their production. Much of this demand is from Italy, where durum is used to make pasta. As Italy is often the single largest importer of Canadian durum, the markets will again watch the European crop closely.

Mexico produces more durum than their population consumes, resulting in Mexico being an exporter of durum and a competitor of Canadian durum exports. The majority of Mexican durum is grown in the Northwest part of the country. Canadian durum prices improve in years when Mexican durum crops have poor yields and / or low quality.

In the Northern Hemisphere, the United States and Canada are the last major exporters of durum to harvest. Durum production in Canada mainly occurs in the southern regions of Alberta and Saskatchewan. In the United States, durum is mainly produced in the state of North Dakota; however, acres can also be found in Minnesota, Montana, South Dakota, and under irrigation in the states of California, Arizona, New Mexico, and a small amount in Idaho.

While Canada and the US export to many of the same countries, Canada historically produces more durum wheat than the US. In addition, the US consumes much of the durum they produce and imports additional durum depending on their local yield and quality. Historically, the US is one of the top five destinations for Canadian durum. In years when US durum yields are good, Canadian exports can suffer from lower demand and competition from US exports. However, when US yields and / or quality are low the demand for Canadian durum is greater and less US wheat ends up competing in export markets.

GRADING GRAIN FROM A PRIMARY PRODUCER DELIVERY AT AN INLAND TERMINAL

Photo credit: SOUTH WEST TERMINALS

What grade is my durum?

The Canadian Grain Commission (CGC) regulates the wheat grading specifications for durum. Their documents can be found by at 'CGC Official Grain Grading Guide' (https://www.grainscanada.gc.ca/og-gg-gocg/ggg-gcg-eng.htm)

There is an exhaustive list of grading factors specified which are used to determine the quality of a producer's durum crop. Grading factors encompass many attributes of the durum wheat which include the colour of the kernels, the presence of disease on kernels, sprouted kernels, ergot bodies, and many more factors.

The durum is given a grade number between 1 and 5, with a number 1 being considered the highest grade of durum.

The grading factors for a number 1 are the strictest. Grading factors become more relaxed as the grade number increases. In practice, grades number 1, 2, and 3 are considered suitable for human consumption, while grades 4 and 5 are considered feed. This results in producers receiving higher prices for higher graded durum wheat.

Down-grading causes significant economic loss (Table 1). Dropping from #1 to #5 CWAD, results in almost $100 / t or about 1/3 of its value. The information on total payments by market class, grade within a class, and protein premiums is no longer disclosed. However, it is expected that the market place today functions in a similar manner.

Protein content is not a grading factor directly. Low protein content may be associated with non-vitreous kernels, which are called variously: non-vitreous kernels, starchy kernels, yellow berry or pie-bald kernels, which can result in lower semolina yield. Consequently, vitreous kernels are preferred over non-vitreous kernels. Both variety and environment determine levels of hard vitreous kernels. Premiums and discounts for protein content may be applied by the buyer (Table 2).

Canada produces high quality durum for the world when the environmental conditions are right. Poor weather can significantly impact durum grading factors and can result in a lower grade. It is important that producers understand what their durum wheat grade is and what their durum protein content is. Producers are encouraged to participate in the Canadian Grain Commission Harvest Sample Program. (https://www.grainscanada.gc.ca/quality-qualite/hsp-per/hspm-mper-eng.htm) Producers should take samples of their grain to multiple buyers who will provide them a grade and a price for their durum. If a producer wants to get an unbiased opinion, there are many labs that will provide results for a fee. The CGC will provide impartial results on a CGC certificate. (https://www.grainscanada.gc.ca/services-services/submits-esoumis/ss-es-eng.htm) Companies such as SGS (http://www.sgs.ca/), BioVision (https://www.biovision.ca/), and Intertek (http://www.intertek.com/canada/) provide many laboratory services, including the grading of grains. Producers can find independent testing using an online search for 'grain laboratory services' or using the website: graintests.com.

TABLE 1. *Total average (2006/7 to 2010/11) prices in Canadian dollars for grades of Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD) and at similar protein levels.*

COMPARISONS BETWEEN CLASSES OF CWRS AND CWAD AT SIMILAR PROTEIN LEVELS

Grade	Protein	Price1	#1-Other difference	#2-Other	#3-Feed
		$Cdn/t	$Cdn/t	$Cdn/t	
#1CWRS	13.5%	$267.87			
#2 CWRS	13.5%	$261.51	$ 6.36		
#3 CWRS	13.5%	$250.81	$ 17.06	$ 10.70	
#4 CWRS		$214.37	$ 53.50	$ 47.14	
C Feed		$187.32	$ 80.55	$ 74.19	$ 63.49
#1 CWAD	13.5%	$287.79			
#2 CWAD	13.5%	$273.55	$ 14.24		
#3 CWAD	13.0%	$257.49	$ 30.30	$ 16.06	
#4 CWAD		$235.64	$ 52.15	$ 37.91	
#5 CWAD		$189.44	$ 98.35	$ 84.11	$ 68.05

TABLE 2. *Total average (2006/7 to 2010/11) prices in Canadian dollars for grades of Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD) and the protein premiums for the upgrades.*

COMPARISONS WITHIN THE #1 GRADE OF CWRS AND CWAD AT DIFFERING PROTEIN LEVELS

Grade	Protein	Price	Protein premium	Protein premium at 0.1 increments $/t
#1CWRS	<11.0%	$241.74		
#1CWRS	13.5%	$267.87	$ 26.13	$1.05
#1CWRS	14.5%	$293.57	$ 25.70	$2.57
#1 CWAD	<11.0%	$274.50		
#1 CWAD	13.5%	$287.79	$ 13.29	$0.53
#1 CWAD	14.5%	$293.57	$ 5.78	$0.58

16. SUSTAINABILITY AND PROFITABILITY TO ENSURE THE FUTURE

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Ensuring a future for both ourselves and others requires openness, compassion, and visionary thinking. There are differing perspectives on many social issues, including sustainability and how it can be achieved. (https://www.footprintnetwork.org/our-work/sustainable-development/)and http://www.thwink.org/sustain/glossary/Sustainability.htm) The idea of sustainability stems from the concept of sustainable development. A frequently used definition of sustainable development is: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Bruntland 1992). Many argue that sustainability has been hijacked and twisted to suit government and business that merely want to continue with business as usual. Others have reframed the definition of sustainability as an ability to continue a defined behaviour indefinitely. (http://www.thwink.org/sustain/glossary/Sustainability.htm) In this definition of sustainability the ability to continue indefinitely is supported by three pillars of sustainability, namely, environmental sustainability, economic sustainability, and social sustainability. To achieve sustainability all three pillars must be sustainable.

Profitability is the primary goal of all businesses including farming. (Profitability: https://www.extension.iastate.edu/agdm/wholefarm/html/c3-24.html) Without profitability the farming enterprise will not survive in the long run. Consequently, measuring current and past profitability, and projecting future profitability are important. Profitability is measured with income and expenses. The tools of accounting, and generation of income statement to assess profitability are components of Smart Farming.

This Durum Production Manual provides an overview of management considerations, principles and resources to contribute to sustainability and profitability for the long term. The focus of the Durum Production Manual is to produce durum wheat in an environmentally sustainable manner. Yet, the production must be done in a manner that is profitable so that farmers have an economic activity that exceeds their opportunity costs.

ALTWASSER FAMILY AND SUSTAINABILITY

Photo credit: SeCan

Durum wheat is a foundational ingredient in the production of food as pasta, semolina, couscous and other food products.

Consumers have high expectations for the production of food that is safe, sustainable, and nutritious. They are interested in how their food is grown, processed and brought to market. The information in this Durum Production Manual provides best management practices for sustainable and environmental sound way to produce durum. Consumers provide a social license in exchange for assurances that their food is produced in an ecologically sound manner that is sustainable.

References

Bruntland, G.H. 1992. Report for the World Commission on Environment and Development: Our Common Future. http://www.un-documents.net/our-common-future.pdf (accessed 14 May 2018)

Additional Information

- **Canadian Wheat Market Classes:** https://www.grainscanada.gc.ca/wheat-ble/classes/classes-eng.htm
- **Converter bus/ac to tonnes/hectare:** http://www.agric.gov.ab.ca/app19/calc/crop/bushel2tonne.jsp
- **General conversion calculator** http://www.kyles-converter.com/
- **Metric Conversions to other scales:** https://www.metric-conversions.org/
- **Keep it Clean:** www.keepingitclean.ca
- **Growth Stages of Wheat:** https://www.usask.ca/agriculture/plantsci/winter_cereals/winter-wheat-production-manual/chapter-10.php
- **Growth Stages of Wheat:** Feekes, Haun and Zadoks Scales: Growth Stages Feekes Haun Zadoks

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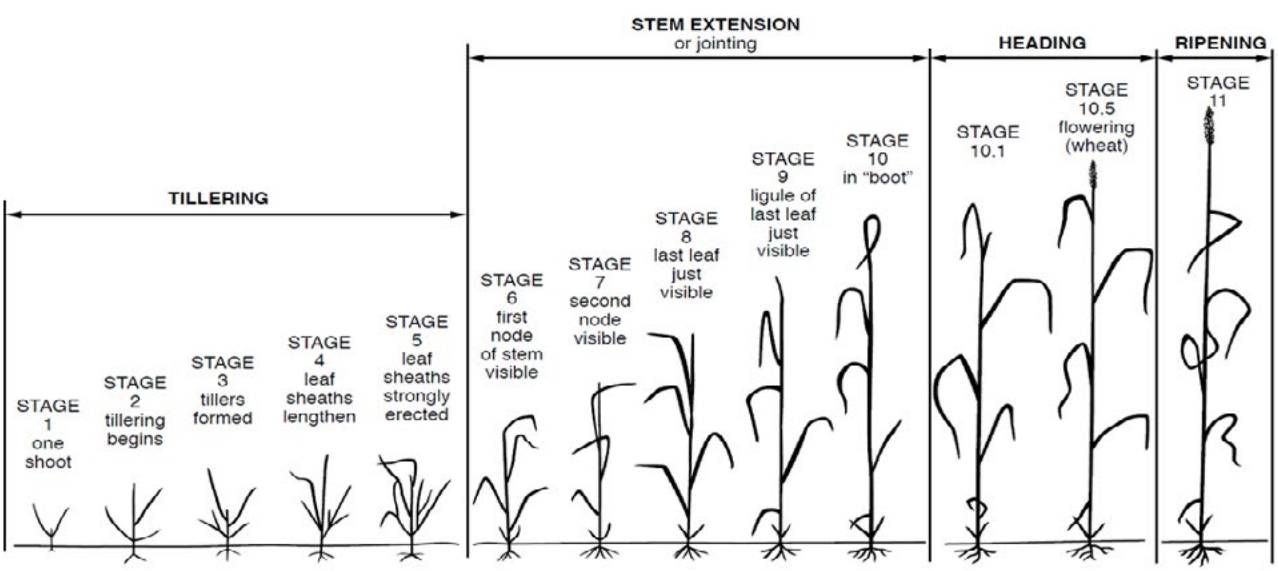
R.M. DePauw, editor, Advancing Wheat Technology, science advisor to SeCan.

Disclaimer

Wheat Growth Stages - Feekes, Haun and Zadoks Scales

Feekes Scale	Haun Scale	Zadoks Scale	General Description
			Germination
		0	Dry seed
		1	Water uptake (imbibition) started
		3	Imbibition complete
		5	Radicle emerged from seed
		7	Coleoptile emerged from seed
	0	9	Leaf just at coleoptile tip
			Seedling Development
1		10	First leaf emerged
	1.+	11	First leaf unfolded
	1.+	12	2 leaves unfolded
	2.+	13	3 leaves unfolded
	3.+	14	4 leaves unfolded
	4.+	15	5 leaves unfolded
	5.+	16	6 leaves unfolded
	6.+	17	7 leaves unfolded
	7.+	18	8 leaves unfolded
	8.+	19	9 or more leaves unfolded
			Tillering
		20	Main shoot only
2		21	Main shoot and 1 tiller
		22	Main shoot and 2 tillers
		23	Main shoot and 3 tillers
		24	Main shoot and 4 tillers
		25	Main shoot and 5 tillers
3		26	Main shoot and 6 tillers
		27	Main shoot and 7 tillers
		28	Main shoot and 8 tillers
		29	Main shoot and 9 or more tillers
			Stem elongation or jointing
4 - 5		30	Pseudo stem erection
6		31	1st node detectable
7		32	2nd node detectable
		33	3rd node detectable
		34	4th node detectable
		35	5th node detectable
		36	6th node detectable
8		37	Flag leaf just visible
9		39	Flag leaf ligule/collar just visible

Feekes Scale	Haun Scale	Zadoks Scale	General Description
			Booting
		40	----
	8 - 9	41	Flag leaf sheath extending
10	9.2	45	Boot just swollen
		47	Flag leaf sheath opening
	10.1	49	First awns visible
			Heading
10.1	10.2	50	First spikelet of head visible
10.2		53	1/4 of head emerged
10.3	10.5	55	1/2 of head emerged
10.4	10.7	57	3/4 of head emerged
10.5	11	59	Emergence of head complete
			Flowering of Anthesis
10.51	11.4	60	Beginning of flowering
	11.5	65	Flowering half complete
	11.6	69	Flowering complete
			Milk
		70	----
10.54	12.1	71	Kernel watery
	13	73	Early milk
11.1		75	Medium milk
		77	Late milk
			Dough
		80	----
	14	83	Early dough
11.2		85	Soft dough
	15	87	Hard dough
			Ripening
		90	----
11.3		91	Kernel hard (difficult to separate by fingernail)
11.4	16	92	Kernel hard
		93	Kernel loosening in daytime
		94	Overripe, straw dead and collapsing
		95	Seed dormant
		96	50% of viable seed germinates
		97	Seed not dormant
		98	Secondary dormancy
		99	Secondary dormancy lost



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SUSTAINABLE PRODUCTION OF

DURUM WHEAT IN CANADA

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