Opportunities to improve yield gaps in rainfed wheat, barley and canola in Alberta

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Introduction

Improving crop yields are essential to meet the increasing pressure of global food demands. The loss of high quality land, the slowing in annual yield increases of major cereals, increasing fertilizer use, and the effect of this on the environment all indicate that we need to develop new strategies to increase grain yields with less impact on the environment. One strategy that could help address this concern is by narrowing the yield gaps of major crops using improved genetics and management. The objective of this study was to determine wheat (*Triticum spp.* L.), barley (*Hordeum vulgare* L.), and canola (*Brassica napus* L.) yields and production gaps in Alberta. We used ten years of data (2005-14) to understand yield variability and input efficiency at a farmers' specified level of management, and the yield potential under optimal management to suggest appropriate pathways for closing yield gaps. This paper identifies yield gaps and offers suggestions to improve efficiency in crop production.

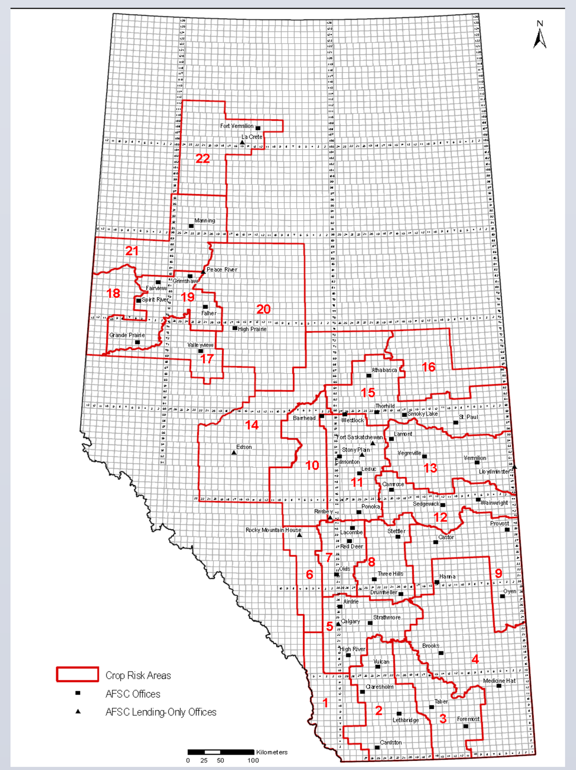
Specific Objectives

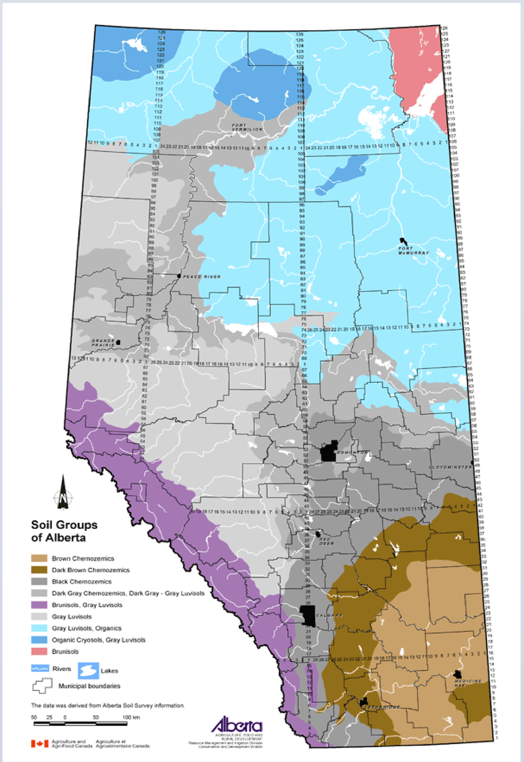
- to calculate crop yield and yield potential for the major field crops, wheat, barley, and canola, in Alberta.
- to identify the gaps that exist between the different measures of yield.
- to discuss possible means to narrow the existing gaps.

Methodology

Data Collection:

- Based on 18 wheat, 20 barley and 22 canola genotypes tested at 21 locations across Alberta over a period of ten years (2005-14).





- Cultivars selected included all those that occupy >1% (10-year's average) of the total cultivated area (AFSC; Agriculture Financial Services Corporation, 2015).
- Actual farm yield (Y_f) and irrigated yields (Y_i) at provincial and regional levels were determined from Statistics Canada (2015) and AFSC (2015), respectively.
- Attainable (Y_a) and maximum attainable (Y_m) yields of wheat, barley, and canola were derived from the farmers' managed crop variety performance trials in the same areas (Alberta Regional Variety Trials - Alberta Agriculture and Rural Development, 2014) that used optimal crop and nutrient management practices.

Yield and Yield Gaps Analysis:

Measures	Definition and Limiting Factors	Data Used	Yield Gaps
Actual farm yield (Y_f)	Average yield of selected cultivars (>1.0%) under rainfed conditions achieved by farmers† Limiting: Moisture, Genetics, Crop management, etc.	Regional statistics (AFSC, 2015; Statistics Canada, 2015)	-
Attainable yield or water limited yield (Y_a)	Average yield for selected (>1.0%) cultivars under rainfed and optimal management conditions, a measure of the benefit of proper crop management† Limiting: Moisture, Genetics	On-farm experiments (AARD, 2014)	Management Gap: $Y_a - Y_f$ (Fischer et al., 2009; Van Ittersum et al., 2013)
Max. attainable yield (Y_m)	Average yield of the top performing cultivar under rainfed and optimal management conditions, a measure of the benefit of genetic selection and optimal crop management† Limiting: Moisture	On-farm experiments (AARD, 2014)	Genetic Gap: $Y_m - Y_a$ Total Gap: $Y_m - Y_f$ (Lobell et al., 2009)
Irrigated yield (Y_i)	Average yield for selected (>1.0%) cultivars under irrigated condition, a measure of the benefit of adequate moisture† Limiting: Other Factors (eg. CO_2, radiation, temperature) ††	Regional Statistics (AFSC, 2015)	Moisture Gap: $Y_i - Y_f$ (Evans, 1993; Van Ittersum and Rabbinge, 1997).
Highest yield (Y_h)	Highest yield recorded during study period	AARD, 2014; Anbessa et al., 2009; Harker et al., 2012	

†All measurement were made for the same regions within Alberta, over the same 10-year period.
††These limiting factors apply to all measurements.

Data Analysis:

- Analysis of variance (ANOVA) for each location as randomized complete block design. A combined analysis of variance from the mean data from each location.
- The software package, Agrobase TM (Agronomix Software Inc., 1990), was used for most statistical analyses.

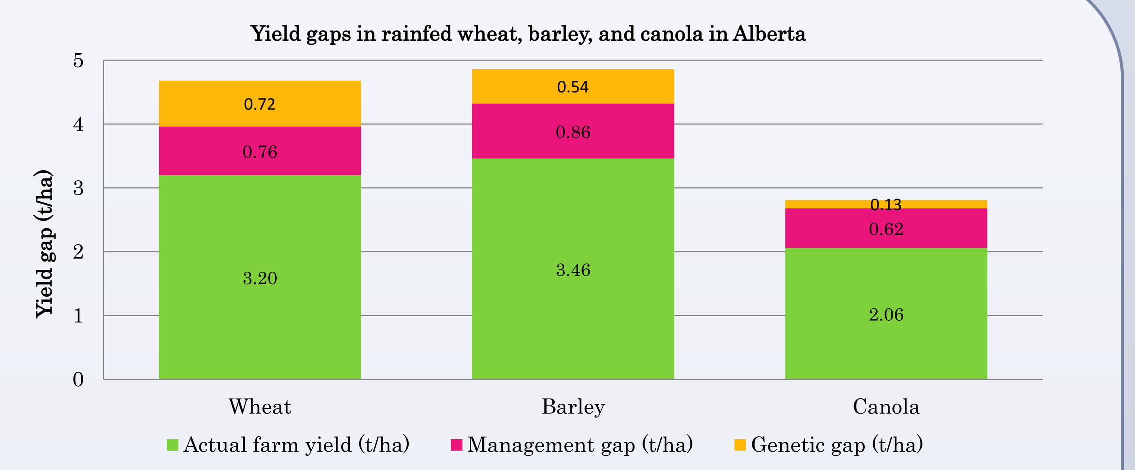
Results

- Significant management gaps were observed due to difference between actual (Y_f) and attainable yields (Y_a) of wheat (an increase of 0.76 t ha^{-1}, 24%), barley (0.86 t ha^{-1}, i.e., 25%), and canola (0.62 t ha^{-1}, i.e., 30%) under rainfed conditions.

Parameters	Alberta			Australia‡	China‡	UK#
	Wheat	Barley	Canola	Wheat	Wheat	Wheat
Rainfall††, mm	245	245	245	182	125	287
CV, rainfall, %	32	32	32	48	55	-
Average N rate, kg ha^{-1} (n = 27)	62	57	74	27	260	190
σ, N rate, (kg ha^{-1})	27	26	31	28	49	-
Average actual yield, (t ha^{-1})	3.20	3.46	2.06	2.27	6.54	8.2
CV, actual, %	17.4	17.8	13.6	65	12	-
Average attainable, (t ha^{-1})	3.96	4.32	2.68	2.21	8.60	10.4
CV, attainable, %	13.1	14.3	8.8	-	-	-
Average max. attainable yield, (t ha^{-1})	4.68	4.86	2.81	-	-	-
CV, max. attainable, %	15.7	17.5	11.7			-
Average irrigated yield, (t ha^{-1})	4.74	4.57	2.77	2.53	10.30	
CV, irrigated, %	16.2	18.7	17.4	-	-	-
Highest yield recorded, (t ha^{-1})	8.41	10.2[1]	4.80[2]	8.00[3]	10.54[4]	15.6[5]

†calculated using secondary data (AFSC, 2015; AARD, 2014; Statistics Canada, 2015),‡ adopted from Carberry *et al.,* 2013; #Fischer *et al.,* 2009, ††average precipitation from seeding (May) to harvesting (August); [1]Anbessa *et al.,* 2009; [2]Harker *et al.,* 2012; [3]CSIRO, 2012; [4]Hou *et al.,* 2012; [5]Farmers Weekly, 2014.

- Average genetic gaps (i.e., the gap between attainable (Y_a) and maximum attainable (Y_m) yields) were 18% (an increase of 0.72 t ha^{-1}) in wheat, 12% (an increase of 0.54 t ha^{-1}) in barley, and 5% (an increase of 0.13 t ha^{-1}) in canola.
- The total gaps (i.e., the gap between actual (Y_f) and maximum attainable (Y_m) yields) were 46%, 40%, and 36% indicating that combination of optimal management practices and genetic selection can increase grain yields up to 4.68 t ha^{-1}, 4.86 t ha^{-1}, and 2.81 t ha^{-1} for rainfed wheat, barley, and canola, respectively, in Alberta.



- The average irrigated yields of wheat, barley, and canola were 4.74 t ha^{-1}, 4.57 t ha^{-1}, and 2.77 t ha^{-1}, showing moisture gaps (i.e., the gap between the irrigated yield and the actual farm yield) of 48% , 32%, and 35%, respectively.
- Management gaps (Y_a-Y_f) ranged between 12-40%, 7-39%, and 15-42% whereas the genetic gaps (Y_m-Y_a) ranged between 10-32%, 11-17%, and 4-5% in rainfed wheat, barley, and canola, respectively.
- Significant variation was observed in the yield of wheat, barley, and canola between genotypes and location under optimal nutrient management. The largest variation was seen between locations (CV = 21.3%), probably due to differences in precipitation and soil type.
- Dark Brown to Black Chernozem soils in Lacombe, Stony Plain, Ft. Kent, and Neapolis produced significantly higher yield under optimal management compared to other locations and showed higher gaps in yield.

Yield Metrics	Yield (t ha^{-1})	Production (million tonnes)	Yield Gain (million tonnes)	Economic Values (million US$†)
Wheat (cultivated area = 2.31 million ha)‡				
Actual Farm Yield (Y_f)	3.20	7.39	-	-
Attainable Yield (Y_a)	3.96	9.15	1.76[1]	395[1]
Max. Attainable Yield (Y_m)	4.68	10.81	3.42[2]	769[2]
Barley (cultivated area = 1.37 million ha) ‡				
Actual Farm Yield (Y_f)	3.46	4.74	-	-
Attainable Yield (Y_a)	4.32	5.92	1.18[1]	183[1]
Max. Attainable Yield (Y_m)	4.86	6.65	1.92[2]	297[2]
Canola (cultivated area = 2.2 million ha) ‡				
Actual Farm Yield (Y_f)	2.06	4.53	-	-
Attainable Yield (Y_a)	2.68	5.89	1.36[1]	466[1]
Max. Attainable Yield (Y_m)	2.81	6.18	1.65[2]	564[2]

†2014-2015 cumulative average price of wheat (US$225 per tonne), barley (US$155 per tonne), and canola (US$342 per tonne) (AAFC, 2015); [1]management gain = $Y_a - Y_f$; and [2]total gain = $Y_m - Y_f$; ‡Statistics Canada, 2015.

- The estimated gain in yields of wheat, barley, and canola due to optimal crop management (i.e., management gain) is 1.76, 1.18, and 1.36 million tonnes, respectively, which was worth $395M, $183M, and $466M (USD) annually, based on 2014-15 cumulative average crop prices.
- Production gains which combined genetic selection (i.e. selection of appropriate cultivars) together with an optimal crop management were found to be 3.42, 1.92, and 1.65 million tonnes of wheat, barley, and canola anually which is equivalent to $769M, $297M, and $564M (USD), respectively.
- The cost of poor genetics (i.e., selection of inappropriate cultivars) was found to be $374M (1.66 million tonnes) in wheat, $115M (0.74 million tonnes) in barley, and $98M (0.29 million tonnes) in canola in Alberta.

Conclusions

- There is a possibility of improving yields of the existing cultivars of wheat, barley, and canola by 24%, 25% and 30%, respectively, by using proper crop management (i.e., soil testing and use of right amount of fertilizer at right time and place, planting density, and pests and disease management).
- Variation was also observed among the genotypes in each location, which offers the opportunity of cultivar selection.
- The combination of optimal crop management practices and selection of location specific cultivars could increase grain yields up to 4.68 t ha^{-1} (46% higher than actual wheat yield), 4.86 t ha^{-1} (40% higher than actual barley yield), and 2.81 t ha^{-1} (36% higher than actual canola yield).
- This might lead to estimated yield gains of 3.42, 1.92, and 1.65 million tonnes of wheat, barley, and canola each year worth $769M, $297M, and $564M (USD), respectively, in Alberta

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