Crop Genetic Improvement:
Genetics, Plant Breeding and Pathology
Crop Development Centre
University of Saskatchewan
Strategic Research Program
2018 - 2023

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1. Introduction

Crop production is the basis for all agriculture, providing the ingredients for food, feed, fibre and biofuel. Saskatchewan farm cash receipts for crops in 2016 was $11.40 billion and for livestock, $1.99 billion (Statistics Canada). Saskatchewan accounts for 47% of the arable cropland in Canada and is a major producer, processor and exporter of wheat, durum, barley, oat, flax, chickpea, lentil, pea, canola, canaryseed, mustard and perennial forage crops.

The Crop Development Centre (CDC) provides genetic research and breeding platforms for developing improved crop varieties of most of the major crop kinds and classes that are important to Saskatchewan and western Canadian farm and industry stakeholders. The CDC has been undertaking this role since 1971 and has a significant track record, releasing over 450 crop varieties and developing significant new crop kinds in that time period, thereby materially contributing to farm and industry diversification, sustainability, and profitability. The economic contribution of the CDC was recently quantified in a study entitled "***Economic Impact of Plant Breeding at the Crop Development Centre***", which showed that between 1991 and 2015, producer profitability increased by $3.8 billion, farm gross output increased by $6.4 billion (in 2015 dollars), and the economic return on investing in plant breeding – an inflation adjusted internal rate of return (IRR) with expenditures from 1971 to 2015 and benefits captured from 1991-2015 was 13.9%. For the same period, the benefit to cost ratio, B/C was 7.1.

To remain relevant as a major source of crop varieties for Saskatchewan and western Canadian producers, the CDC recently developed a vision document, "*Taking Aim at the Future*", and revised it vision and mission:

> The CDC vision is to be "***a world-class crop improvement Centre that delivers crop genetics for society***", with the accompanying mission to "***develop crop varieties that bring value to the agriculture sector, through the development and application of scientific knowledge and technologies, in partnership with stakeholders across the agriculture value chain***".

From 2018-2023, the CDC Strategic Research Program (SRP) will allow CDC scientists to focus on improving the agronomic performance and the food and nutritional quality characteristics of pulse crops, cereals and flax for food, feed, and industrial uses. Tied to this objective is diversification within these crops to allow for development of new crop kinds, specialty varieties and market classes that add value and provide the basis for value added processing and marketing to specialty end-users. The establishment of a SRP program in forage crop breeding at the CDC is important not only for crop diversification purpose; this program will serve the ever-growing provincial livestock enterprises including beef, dairy, sheep, and bison. The CDC recognizes that traditional field crops (cereals, pulses, and oilseed) will continue to dominate the

arable landscape of the province, and thus research aimed at the major market classes will constitute the majority of research effort. As well, we will also continue our success in developing new crop kinds and uses such as canaryseed, spelt and pigmented wheat. Fababean is becoming an important crop, especially for protein extraction because it produces more protein per acre than any pulse crop currently grown. Efforts will target the development of small-seeded, low vicine/convicine types and their accelerated release for commercial production.

Crop diseases and insect pests continue to be serious constraints to crop production in Saskatchewan and, as a result, CDC plant breeding programs place a high priority on breeding for genetic resistance. Genetic resistance to diseases and insects improves crop yield and quality, reduces the cost of production by reducing the application of chemical fungicides/insecticides, minimizes production risk and contributes to long-term economic and environmental sustainability. The current complement of one plant pathologist for cereals and flax and one for pulse crops is providing scientific support to the breeding programs. The recent recruitment of an entomologist in the Department of Plant Sciences provides an opportunity to conduct cutting edge research to manage insect pests.

All CDC breeding programs currently utilize genomic tools to facilitate the development and deployment of agronomic, abiotic and biotic stress resistance and quality traits into their germplasm to improve the efficiency of selecting varieties with desirable traits. Funding from a variety of public and private stakeholders and collaborations with national and international institutions provide the financial and technical resources for developing genomic tools.

2. CDC Overall Strategic Goal

The long term strategic goal of the CDC is to increase the profitability and sustainability of crop production in Saskatchewan by utilizing the relevant leading-edge scientific and technological tools to develop new and improved crop varieties, and contribute to the provincial government's "Growth Plan" objective of increasing crop production.

3. General Research and Program Activities 2018-2023

3.1 Plant Breeders

- Crop breeding with general breeding objectives to improve agronomic traits – disease and insect resistance, adaptation to the prairie production environment, resistance to lodging and shattering, enhanced yield potential, improved environmental stress tolerance.
- Crop breeding with general breeding objectives to improve quality traits – to enhance levels of desirable macro and micronutrients in the seed, reduce levels of undesirable quality factors and modify chemical composition to develop new uses for crops and crop components.
- Introduction, evaluation and utilization of new and unique germplasm.
- Development and/or evaluation of new breeding techniques (NBTs such as genomic selection and next generation genotyping systems), methods and equipment that are highly relevant to crop breeding.

- Collaboration with scientists at the University of Saskatchewan and other national and international research institutions, where appropriate, in basic scientific research and plant breeding programs.
- Collaboration in technology transfer in crop management and variety commercialization to the Saskatchewan and Canadian industry.
- Participation in scholarly activities related to scientific advancement, scientific publication, and training of new scientists.
- Participation in research and industry committees and advisory boards where applicable and appropriate.
- Investigation of new funding opportunities and management of existing funding including reporting requirements.
- Teaching of undergraduate and graduate level courses as appropriate.

3.2 Plant Pathologists

- Research to gain a better understanding of disease biology, pathogenic variation, disease epidemiology and pathogen-host relationships.
- Identification of new and suitable sources of resistance for use in the CDC plant breeding programs.
- Screening of CDC breeding material for disease resistance.
- Development and refinement of integrated disease management strategies, including fungicide timing and rotation studies.
- Collaboration with scientists at the University of Saskatchewan and other scientific institutions, where appropriate, including the provincial disease specialist, in basic scientific research, disease surveillance and plant breeding programs.
- Collaboration in technology transfer in crop management and variety commercialization to the Saskatchewan and Canadian industry.
- Participation in scholarly activities related to scientific advancement, scientific publication, and training of new scientists.
- Participation in industry committees and advisory boards where applicable and appropriate.
- Investigation of new funding opportunities and management of existing funding including reporting requirements.
- Teaching undergraduate and graduate courses.

4. Specific Research and Program Objectives by Crop Kind and Class 2018-2023

4.1 Pulse Crops

4.1.1 Field Pea – Dr. Tom Warkentin

- Develop high yielding yellow, green and specialty market class field pea cultivars with resistance to powdery mildew, improved resistance to the ascochyta blight complex, root rots, and lodging, and improved end-use quality for export and domestic markets. Disease resistance work will be conducted in collaboration with the CDC Pulse Pathologist, as well as with national and international collaborators.

- Collaborative research to identify pea germplasm with enhanced resistance to environmental stresses, particularly heat and drought, and to introgress these resistances into cultivars.
- Improve the market value of field pea in terms of visual appearance, nutritional value, culinary properties, flavour profile, and functional properties including milling, baking, and cooking.
- Development and utilization of genomic tools including high density genetic maps, whole genome sequence, and effective and efficient molecular markers for use in marker assisted selection for key traits of interest in breeding.
- Development and implementation of improved genotyping and phenotyping approaches.

4.1.2 Soybean: Dr. Tom Warkentin

- Develop maturity group 000, high-yielding soybean cultivars with acceptable protein and oil composition and acceptable disease and insect resistance for Saskatchewan and western Canadian conditions.

4.1.3 Chickpea: *Chickpea breeding was supervised by Dr. Buyamin Tar'an as the Agri-Food Innovation Fund (AFIF) Chair from 2018-2021. Later the Chickpea breeding objectives were moved under the Strategic Research Program under the supervision of Dr. Bunyamin Tar'an as the Chickpea and Flax Genetics and Breeding Chair in 2021. Learn more about the updated objectives.*

- Overall objective: Develop high yielding chickpea cultivars with improved agronomic performance and end-use quality.
- Develop early maturing cultivars with durable Ascochyta blight disease resistance and expanded herbicide options.
- Improve visual seed quality characteristics.
- Improve intrinsic seed quality profiles for human nutrition.
- Develop specialty varieties targeting niche markets to increase diversity and opportunities;
- Develop germplasm resource for use in future chickpea improvement.
- Develop and apply genomic-assisted breeding strategies to enhance chickpea cultivar development.

Kabuli chickpea specific objectives:

- Develop cultivars with improved seed size, acceptable visual seed characteristics and canning/cooking quality.
- Develop specialty kabuli chickpeas for niche markets.

Desi chickpea specific objectives:

- Develop cultivars with acceptable visual seed characteristics (shape, size, and colour) and acceptable dehulling and milling quality.
- Develop specialty desi chickpeas for niche markets.

4.1.4 Lentil: *Lentil breeding is being supervised by Dr. Bert Vandenberg of the CDC, as an Industry Research Chair funded by NSERC and Saskatchewan Pulse Growers.*

- Genetic improvement of yield, adaptation, lodging tolerance, and herbicide tolerance options for producers.

- Genetic improvement of biotic stresses including resistance to ascochyta blight, anthracnose, stemphylium blight, and other emerging pathogens in all commercial market classes of green, red and specialty lentil classes. Disease resistance work will be conducted in collaboration with the CDC Pulse Pathologist.
- Genetic improvement of culinary, physical, nutritional quality and processing properties of seed appropriate for specific lentil market classes in global markets.
- Expanded market classes with high value niche/specialty output traits.
- Develop and apply where appropriate genomic/molecular breeding and rapid generation advance technologies.
- Develop appropriate genetic resources for use in future lentil crop improvement strategies.

4.1.5 Faba Bean: *Faba bean breeding is being co-supervised by Dr. Bert Vandenberg and Dr. Bunyamin Taran under the Pulse Crop Breeding program at the CDC and funded in part by the Saskatchewan Pulse Growers.*

- Overall objective**:** Develop high yielding faba bean cultivars with improved adaptation to western Canada agro-ecological zones, improved agronomic performance and end-use quality.
- Develop low vicine/convicine, small-seeded zero-tannin cultivars.
- Develop large-seeded food type faba bean cultivars.
- Improve resistance to chocolate spot disease;
- Develop early maturing cultivars.
- Improve lodging resistance.
- Develop germplasm lines for use in future faba bean genetic improvement.

4.1.6 Dry Bean: *Dry Bean breeding is being supervised by Dr. Kirstin Bett from the Dept. of Plant Sciences as an integral part of the Pulse Crop Breeding program at the CDC.*

- Focus on black, yellow and pinto beans market classes.
- Genetic improvement of yield, adaptation, early maturity with Type II growth habit, high pod clearance, cold tolerance as well as resistance to common bacterial blight, anthracnose and other emerging pathogens.
- Disease resistance work will be conducted in collaboration with the CDC Pulse Pathologist.
- Genetic improvement of culinary, physical and nutritional quality traits that are specific to each market class.
- Development and use of molecular markers for traits such as disease resistance (common bacterial blight and anthracnose) as well as seed coat quality traits (colour and colour retention).
- Development of varieties that can be direct-harvested to expand acreage.
- Explore and develop tepary bean as a niche market crop.

4.1.7 Pulse Pathology: Dr. Sabine Banniza

- Support efforts in continuously improving resistance to the major diseases, in developing varieties with resistance to the secondary diseases, and in screening for resistance to potentially new diseases.
- Monitor changes in pathogen populations in order to develop suitable screening protocols for disease resistance screening, and adapt disease management strategies accordingly.
- Investigate the biology of newly emerging diseases with the objective to support breeding efforts, assess the economic importance of these diseases and lay the foundation for further research into disease management strategies, if required.
- Research the host-pathogen interactions in pulse crops to gain a better understanding on how resistance in pulse crops function and why it can break down.
- Develop disease management strategies for pathogens of economic importance in pea, lentil, chickpea, field bean, faba bean and soybean in Saskatchewan.

4.2 Flax: Dr. Bunyamin Tar'an (2021)

Develop cultivars with significantly improved agronomic traits, including yield, timely maturity, medium to large seed size, and durable disease resistance and seed quality traits of interest to the market. Specific objectives that address the key challenges include:

- Providing a genetic or yield (seed yield and seed weight) gain of 5.0% better than relevant reference cultivar per cultivar release.
- Developing and selecting for crop characteristics associated with yield production and ease of harvest in the Canadian prairies, including early season vigour, timely maturity, determinant growth habit, stem/straw dry down and straw manageability.
- Explore bast fibre crop characteristics as they relate to straw management issues. Advancing a genetic approach to develop flax with straw that can be easily managed during and after harvest.
- Developing and selecting for seed quality traits of commercial importance (e.g., oil and protein content, oil profile).
- Explore variation in uniformity in flaxseed coat color and anti-nutritionals (e.g., cyanogenic glycosides and cadmium) and investigate inheritance and selectability of these characteristics.
- Maintain and improve durability of disease resistance to flax rust, and advance disease resistance to fusarium wilt, powdery mildew, and pasmo (in collaboration with the CDC Cereal & Flax Pathologist).
- Incorporate molecular marker assisted selection (MMAS) and other molecular breeding tools for important traits in flax where appropriate and applicable (e.g., seed coat colour, flax rust, powdery mildew resistance) to increase efficiency of selection.

4.3 Spring Wheat: Dr. Pierre Hucl

- Develop Canada Western Red Spring (CWRS - ongoing), Canada Western Hard White Spring (CWHWS – phase out by 2023) and Canada Northern Hard Red (CNHR – phase in starting in 2018) wheat cultivars adapted to Saskatchewan and adjoining regions with improved yield-maturity relationships, quality and disease resistance.
- Develop shorter-strawed, medium maturity varieties.

- Incorporate new sources of disease and insect resistance into the existing CDC germplasm base. Incorporate and evaluate new and existing sources of fusarium head blight (FHB) including DON mycotoxins, stripe rust and wheat midge resistance. Disease resistance investigations will be carried out in collaboration with the CDC Cereal Pathologist.
- Investigate, develop and utilize molecular breeding techniques where applicable and appropriate.

4.4 Specialty wheat and canaryseed: Dr. Pierre Hucl

- Introduce and evaluate unique wheat germplasm for alternate end-use suitability and adaptation to Saskatchewan growing conditions.
- Develop specialty wheat and canaryseed cultivars (glabrous; brown or yellow-seeded) adapted to Saskatchewan and adjoining regions with improved yield-maturity relationships and quality characteristics that enhance marketability.
- Specific objectives will vary with each species depending upon the major agronomic and quality constraints.

4.5 High yielding wheat: Dr. Curtis Pozniak

- Develop red-seeded high yielding wheat cultivars adapted to Saskatchewan with milling grade quality (medium protein, acceptable gluten strength, superior flour colour) with acceptable maturity, and improved disease resistance (particularly fusarium head blight resistance). Emphasis on quality characteristics for the Canada Prairie Spring Red (CPS-R) class will be our priority. Disease resistance investigations will be carried out in collaboration with the CDC Cereal Pathologist.
- Continue incorporation of leaf, stripe and stem rust resistance, and resistance to FHB including DON mycotoxins into high yielding wheat genetic backgrounds.
- Develop and utilize molecular/genomic strategies to improve selection efficiency through marker assisted selection and novel strategies (genomic selection).

4.6 Durum wheat: Dr. Curtis Pozniak

- Develop low cadmium uptake durum wheat cultivars adapted to the western Canadian prairies with improved grain yield potential, appropriate maturity, and grade retention and acceptable end-use quality suitable for the CWAD class. Cultivars will have acceptable disease resistance.
- Develop durum wheat cultivars with improved pest resistance, with emphasis on leaf, stem and stripe rust and leaf spotting diseases and the wheat stem sawfly (western Saskatchewan), and Fusarium head blight and midge resistance (eastern prairies). Emphasis over the next five years will be in particular to improve FHB resistance in durum wheat (including reducing levels of grain mycotoxins produced by *Fusarium spp.*). Disease resistance investigations will be carried out in collaboration with the CDC Cereal Pathologist.
- Continue our world-class research in develop and utilize molecular/genomic strategies to improve selection efficiency through marker assisted selection, genomic selection and other novel strategies (including the potential use of NBTs such as genomic selection and next generation genotyping technologies.).

4.7 Malt, Feed, Forage and Food Barley: Dr. Aaron Beattie

- Emphasis will be placed primarily on hulled two-row malting barley (for brewing) and hulled two-row feed barley. Lower emphasis will be placed on hulled two-row malting barley (for distilling), forage barley and hulless two-row malting and food (including black aleurone) barley.
- Increase the probability of successful production (sustainability) by decreasing production risks from diseases. Priority diseases will be FHB (including DON mycotoxins), scald, net blotch, spot blotch, stem rust and smuts. Disease resistance investigations will be carried out in collaboration with the CDC Cereal Pathologist.
- Improve productivity through yield gains and improve harvestability through earlier maturity, reduced plant height and better lodging and shattering resistance.
- Maintain and increase domestic and international value (marketability) of barley via improved grain quality. Priority physical traits will be plumpness, test weight, thousand kernel weight for all barley types, low peeling, colour and sprouting for malting barley, and threshability for hulless barley. Priority quality traits will be higher extract, higher free amino nitrogen, lower protein and lower β-glucan content in malting and distilling barley, higher protein and digestibility in feed and forage barley, high β-glucan content and black aleurone in food barley.
- Introduce and evaluate novel germplasm for suitability for use in developing cultivars adapted to Saskatchewan conditions.
- Innovate in breeding technology and germplasm development (e.g. molecular markers, genome-wide selection, near-infrared spectroscopy (NIR), and field phenotyping).

4.8 Milling and Forage Oat: Dr. Aaron Beattie

- Emphasis will be placed primarily on milling oat with lower emphasis on forage oat.
- Increase the probability of successful production (sustainability) by decreasing production risks from diseases. Priority diseases will be crown rust, stem rust, smuts, FHB (including DON mycotoxins) and barley yellow dwarf virus (BYDV). Disease resistance investigations will be carried out in collaboration with the CDC Cereal Pathologist.
- Improve productivity through yield gains and improve harvestability through earlier maturity, reduced plant height and better lodging resistance.
- Maintain and increase domestic and international value (marketability) of oat via improved grain quality. Priority physical traits will be plumpness, test weight, thousand kernel weight and improved groat percentage. Priority quality traits will be higher protein, β-glucan and total dietary fibre (TDF) content, and lower oil content.
- Introduce and evaluate novel germplasm for suitability for use in developing cultivars adapted to Saskatchewan conditions.
- Innovate in breeding technology and germplasm development (e.g. molecular markers, genome-wide selection, NIR, field phenotyping).

4.9 Cereal and Flax Pathology: Dr. Randy Kutcher

- The overall objective of the cereal and flax pathology program is to advance knowledge of host-pathogen genetic interactions and integrated disease management, and to apply this information in the development of cereal and flax cultivars, and as a basis for best

management practices for production of these crops in Saskatchewan and western Canada.

Specific objectives

- Support breeding efforts to improve or maintain host resistance to the major diseases (rusts and FHB of cereals, and pasmo and fusarium wilt of flax), improve resistance to the secondary diseases (leaf spotting diseases, viral diseases and root rots of cereals, and powdery mildew and rust of flax), and to identify resistance to potentially new diseases.
- Identify sources of resistance, study the inheritance of host resistance, and transfer resistance into elite germplasm.
- Assess virulence variability in pathogen populations, and monitor virulence over time to ensure the deployment of effective resistance genes.
- Investigate the economic importance of new diseases, study the epidemiology, investigate control measures, and develop protocols for germplasm screening.
- Study the genetic basis of host-pathogen interactions with the goal of understanding plant pathogenesis and developing cultivars with durable disease resistance.
- Develop integrated disease management strategies (cultural and chemical, as well as varietal resistance) for pathogens, particularly FHB, of economic importance in Saskatchewan.
- Contribute to the surveillance of existing pathogens and identify new pathogens as they arise in Saskatchewan.

5. Program Outputs

5.1 Program Outputs for Plant Breeders

- New crop cultivars with improved agronomic and quality traits.
- Greater understanding of crop genetics and genomics.
- Molecular marker assisted selection (MMAS) and other molecular breeding tools for key traits in the crop where appropriate and applicable.
- Scientific, peer reviewed manuscripts, and presentations at scientific conferences.
- Outreach and technology transfer activities through presentations at producer and industry meetings, and contributions to industry advisory panels.
- Involvement in training of new scientists.
- Undergraduate and graduate student supervision.
- Teaching of undergraduate and graduate level courses, while not exceeding 10% of this time commitment.

5.2 Program Outputs for Plant Pathologists

- Contribute to the development of new crop cultivars with improved disease resistance.
- Increase our understanding of disease biology, pathogenic variation, disease epidemiology and pathogen-host relationships.
- Selection strategies and techniques for use in breeding resistance to existing and emerging disease threats to pulses, flax and cereals.
- Contribute to molecular marker development for key diseases in relevant crops.
- Scientific and peer reviewed manuscripts.

- Outreach and technology transfer activities through industry media, presentations at producer and industry meetings and scientific conferences.
- Scholarly activities including scientific publications and presentations.
- Undergraduate and graduate student supervision.
- Teaching of undergraduate and graduate level courses, while not exceeding 10% of this time commitment.
- Contribute to provincial disease surveys where appropriate.

6. Program Outcomes

6.1 Program Outcomes for Plant Breeders

- Increased economic activity within Saskatchewan through continued release of cereal, flax, pulse and forage crop varieties.
- Enhanced crop productivity and reduced crop production costs and risk.
- Increased demand for Saskatchewan grains in export markets.
- Profitable crop and livestock production and increased value-added processing within the province.
- Greater diversification of crop kinds, specialty varieties, market classes and quality profiles to expand domestic and export market opportunities.

6.2 Program Outcomes for Plant Pathologists

- Increased profitability and sustainability of crop production in Saskatchewan.
- Enhanced crop productivity and reduced crop production costs and risk.
- Enhanced understanding of the major diseases affecting pulse, flax, canaryseed, cereal and forage crops.
- Integrated disease management approaches to pulse, flax, canaryseed and cereal disease mitigation in Saskatchewan.

7. Forage Crop Breeding: Dr. Bill Biligetu

7.1 Introduction:

Forage crops are the foundation of livestock enterprises including beef, dairy, sheep, bison and horses in Saskatchewan with approximately 36% of total farm areas dedicated to forage production. The beef industry alone has close to three million cattle and calves in the province. There are also thriving forage seed and leaf-cutter bee sectors, which also contributed to the provincial economy. In addition, perennial forage crops enable more sustainable agricultural systems by reducing soil erosion, and sequestering carbon to reduce greenhouse gas emissions.

A review of beef, feed and forage research and development activities done by MNP in 2011 identified forages as a priority area for research. Expanded investment in forage infrastructure and research has been recommended, with a specific recommendation for an additional Strategic Research Program (SRP) in forage breeding. In 2014, a SRP chair in forage crop breeding was established at the Crop Development (CDC) of the University of Saskatchewan. Breeding of

improved forage cultivars under the SRP program is critical for Saskatchewan livestock and forage industries to remain competitive on a global scale by supplying stable, low cost feed.

The forage breeding program at the CDC aligns with the overall Vision and Mission of the Crop Development Center to increase the profitability and sustainability of crop production in Saskatchewan by developing new and improved cultivars of forage crops. This program will collaborate with forage breeders and scientists around the globe to enhance knowledge and germplasm exchange, and promote application of cutting edge technology in forage breeding.

7.2. General Research and Program Activities 2013-2018

- The improvement of agronomic traits in forage crops through breeding: – i.e, disease resistance, adaptation to the prairie production environment, enhanced yield potential, and improved abiotic stress tolerance.
- The improvement of quality traits in forage crops through breeding: i.e., enhanced levels of desirable macro and micronutrients in the forage crops.
- Introduction, evaluation and utilization of new and unique germplasms.
- Development and/or evaluation of new breeding technologies and methods.
- Collaboration with scientists at the University of Saskatchewan and other scientific institutions, where appropriate, in basic scientific research and plant breeding programs.
- Collaboration in technology transfer in forage management and variety commercialization to the Saskatchewan and Canadian industry.
- Participation in scholarly activities related to scientific advancement, scientific publication, and training of new scientists.
- Participation in research and industry committees and advisory boards where applicable and appropriate.
- Investigation of new funding opportunities and management of existing funding including reporting requirements.
- Teaching of undergraduate and graduate level courses as appropriate. Teaching of graduate and undergraduate courses not to exceed 10% of this time commitment.

7.3. Specific Research Goals of Forage Breeding Program during 2018-2023:

- Develop high yielding alfalfa cultivars adapted to the prairie regions of Canada with acceptable resistance to bacteria wilt, verticilium wilt, and other root diseases, persistence under intensive use.
- Develop sainfoin cultivars with improved winter hardiness, and high forage and seed yields.
- Develop hybrid bromegrass cultivars with improved seed yield, resistance to leaf brown spot disease, improved fiber digestibility. Fiber digestibility work will be carried out in collaboration with the Animal Sci. Department.
- Develop meadow bromegrass with improved regrowth in the late growing season

- Develop crested wheatgrass cultivars with later maturity, and select for high leaf-to-stem at plant heading to improve forage quality.
- Develop hybrid wheatgrass with improved seed yield, acceptable salinity tolerance
- Introduce/evaluate new legume crop – forage Galega.
- Introduce/evaluate new grass/alfalfa germplasm in collaboration with the North American Forage Breeder's working group.
- Develop NIR prediction equations of major forage nutritive traits for all forages species
- In collaborating with molecular biologist/Quebec forage groups, evaluate genomic selection of alfalfa.

7.4. Program Outputs:

- Higher yielding cultivars (either biomass or seed yield).
- Higher quality cultivars (NDF digestibility, later maturing type).
- More stress tolerant cultivars (salinity tolerance, tolerance to intensive use).
- Sequence or partial sequence of genomes of alfalfa, crested wheatgrass,
- Genomic selection, prediction models.
- Scientific, peer reviewed manuscripts, and presentations at scientific conferences.
- Outreach and technology transfer activities through presentations at producer and industry meetings, and contributions to industry advisory panels.
- Involvement in training of new scientists.
- Undergraduate and graduate student supervision.
- Teaching of undergraduate and graduate level courses, as assigned. Teaching of graduate and undergraduate courses not to exceed 10% of this time commitment.