AgriScience Program - Projects Component

Annual Performance Report

Name of Recipient: Canadian Field Crop Research Alliance (CFCRA)	
Project Title: Breeding, genomics, and agronomy research to improve oat yield and quality	
Project Number: ASP-001	**Period Covered by the Report**: 2020/04/01 to 2021/03/31
Project Start Date: 2018/04/01	**Project End Date**: 2023/03/31

1. Performance Measures – Project Level

In the performance measures table below, please provide the results and achievements that were finalized during the reporting period, that combines all the CA and CRDA activities. Do not include results that are not final or that will continue to be developed. It is quite possible that in the first year or two, there may not be any results to report. Please see Annex A for a description of each performance measure.

	Performance Measure	**Results Achieved**	Provide a brief description of each final result achieved during the reporting period.
1.	Number of highly qualified personnel (HQP) working on funded activities (HQP refers exclusively to current Master and PhD students)	0	
2.	Training/knowledge transfer events		
	2.1 Number of training/knowledge transfer events organized by the recipient	0	
	2.2 Number of presentations made in training/knowledge transfer events	1	1. Presented by Weikai Yan. Ottawa Field Day for SeCan, Ottawa Field Day, AAFC Ottawa Research Station, July 22, 2020.
3.	Number of participants at training/knowledge transfer events	1	1. Phil Bailey of SeCan in the field tour, July 22, 2020.
4.	Number of new knowledge transfer products developed	1	1. Two replicates are sufficient for cereal crop variety trials in Ontario (Yan, W., January 2021, written report to industry reps)
5.	Number of papers published in peer reviewed journals	5	1. Yan, W., Mitchell-Fetch, J., Betties, A., Nilsen, K., Pageau, D., DeHaan, B., Hayes, M., Mountain, N., Cummiskey, A. and MacEachern, D., Oat mega-environments

Performance Measure		Results Achieved	Provide a brief description of each final result achieved during the reporting period.
			in Canada. Crop Science. doi.org/10.1002/csc2.20426 2. Yan, W., Fregeau-Reid, J., deHann, B., Thomas, S., Hayes, M., Martin, R., Cummiskey, A., Pageau, D., Morasse, I., Jakubinek, K. and Xue, A., 2020. AAC Banner Oat. Canadian Journal of Plant Science, (ja). doi.org/10.1139/CJPS-2019-0341 3. Yan, W., 2020. Estimation of the optimal number of replicates in crop variety trials. Frontiers in Plant Science, 11. DOI: 10.3389/fpls.2020.590762 4. Fetch, T., Mitchell, Fetch, J., Zegeye, T, Xue, A.G. 2020. Races of Puccinia graminis on barley, oat, and wheat in Canada from 2015 to 2019. Can J Plant Pathol. 42: 1 doi.org/10.1080/07060661.2020.1829066 . 5. Xue, A.G., and Chen, Y. 2020. Diseases of oat in Ontario in 2019. Can. J. Plant Pathol. 42 (Suppl.): 65-6666. DOI:10.1080/07060661.2020.1752524.
6.	Number of new technologies (new products, practices, processes and systems) that are developed		
7.	Number of new technologies (new products, practices, processes and systems) that are assessed under research conditions		
8.	Number of new technologies (new products, practices, processes and systems) that are demonstrated on-farm or in-plant		
9.	Number of new technologies (new products, practices, processes and systems) that attain Intellectual Property (IP) protection.	5	1. OA1444-5-19 oat (SeCan) 2. OA1598-1 oat 3. OA1613-5 oat 4. OA1609-7 oat (SeCan) 5. OA1610-6 oat
10.	Number of new technologies (new products, practices, processes and systems) that are utilized		

2. Activity-level Information

In this section, please complete one table for each activity. For activities with both a CA and CRDA

component, please integrate the results into one table.

CA Activity Number: 1B / CRDA Activity Number: 1A
Name of Activity: Breeding, genomics and agronomy research to improve oat yield and quality
Principal Investigator: Weikai Yan
Summary of Activity Please provide a high-level summary of this activity that includes an introduction, objectives, methodology, deliverables, results and discussion. Technical language can be used in this section.

INTRODUCTION

Oat is an important, multi-purpose cereal in Canada that is grown for grain, straw, forage, or land cover. Oat grain is regarded as a healthy human food, largely due to the presence of beta-glucan (BGL) and other soluble fibers in the oat groat, which have been implicated in reduced risk of heart disease, lowered blood pressure, and lowered risk of type-II diabetes. Grain yield, groat content (i.e., milling yield), and BGL content are key targets for improvement. Protein, test weight, and kernel weight are considered secondary targets for improvement. Additionally, oat millers require a groat oil content of less than 8% to meet the FDA healthy food labeling requirements. To achieve high and stable yield and quality, lodging resistance is required under high-yielding environments, and resistance to crown rust is required in some production regions. Our nation-wide multi-disciplinary research team proposes to improve these characters through breeding, genomics, and agronomy. There are seven objectives in this proposed project: 1) developing new oat cultivars with improved grain yield and quality; 2) identifying optimal agronomic practices to achieve high and stable grain yield and quality; 3) enhancing the current oat breeding procedures in both the Ottawa and Brandon programs with genomic selection; 4) improving the ability to deploy appropriate rust resistance genes through a survey of Pc gene profiles in existing cultivars, and Pc gene effectiveness in western and eastern Canada; 5) enhancing genetic diversity in North American oat breeding programs through a joint testing and genotyping network that promotes germplasm exchange and provides information about adaptation; and 6) developing a multi-faceted approach to data and knowledge management that enhances all objectives of this project and benefits world-wide pre-competitive oat research. Collectively, these six objectives share the same ultimate goal to improve Canadian oat grain yield and quality. The expected impacts on the Canadian field crop sector include: 1) increased income for Canadian oat growers, 2) increased profit of Canadian/American oat processors, 3) increased health of oat consumers, 4) increased resilience of Canadian agriculture against biotic and abiotic stresses and adaptation to climate change, and 5) enhanced Canadian soil and environmental conservation due to the planting of more oats in rotation with other crops. Through these outcomes, this project addresses the following AAFC priorities: 1) to enhance Canadian environmental sustainability in the face of climate change, and 2) to enhance knowledge and technology transfer activities and thereby the resiliency and productivity of the agriculture.

OBJECTIVES

Objective #1: Cultivar development

• By 2023, to release at least one new cultivar for subregion1, with ≥11% higher grain yield than the mean of check cultivars AAC Bullet and AAC Roskens while keeping the groat level of the check cultivars (≥72%) (High b-glucan is not required for oat grain not used for milling).

• By 2023, to release at least one new cultivar for subregion2, with ≥11% higher yield than the mean of check cultivars AC Rigodon, Dieter, and Synextra while keeping the beta-glucan (≥4.2%) and groat (≥72%) levels of the check cultivars.

• By 2023, to release at least one cultivar for subregion2, with ≥5.0% beta-glucan while keeping the yield and groat levels of the check cultivars AC Rigodon, Dieter, and Synextra.

Objective #2: Agronomic research to develop oat production guide

• Cultivar and region-specific production guide on N rate and method and planting density if there are genotype by treatment and region by treatment interactions.

• Scientific manuscripts reporting the research

Objective #3: Genomic selection

• GS derived lines from this project are at an advanced stage of performance testing, and GS

lines from the GFII project could be recommended as varieties.
• Scientific report on the relative efficiency of GS vs. visual selection.
• Recommendation on the use of GS in future oat breeding within Ottawa and Brandon oat breeding programs.
• Genotype and phenotype database, and highly predictive GS models for ongoing use.

Objective #4: Pyramiding crown rust resistance using gene markers
• 2018: data on crown rust response of two populations (10W60 and 15F082)
• 2018: Genotype data of the two populations
• 2019: Selectable markers for PcTX, Pc59, and/or Pc61.
• By 2022, >10 crown rust resistant lines
• By 2022, >1 oat line carrying ≥3 Pc genes

Objective #5: Crown rust pathogen virulence and host resistance gene survey
• Report on the crown rust rating of the oat crown rust differential lines tested in Ottawa and Morden (Yan, Menzies)
• Survey report of oat field in eastern Canada and western Canada and publish the annual survey report (Menzies and Xue)
• Report of reactions of newly released oat cultivars and promising lines to different crown rust races (Menzies)

Objective #6: North American joint oat breeding and testing
Yearly data of grain yield, agronomic traits, grain quality, any diseases, and compositional quality for c. 240 new breeding lines from 4 breeding programs at 5 locations (Ottawa, Brandon, Saskatoon, Lacombe, and Fargo) (Yan, Mitchell Fetch, Beattie, and McMullen)

Objective #7: Oat Data and Knowledge Management
All interim database deliverables were populated and enhanced until project completion. An overall project report describing project accomplishments in knowledge management is published.

MILESTONES

Objective #1: Cultivar development (yearly)
1) About 50 new crosses
2) About 300 F4:5 or F6:7 lines, to be tested in next year's Home Test.
3) Yield and quality data of c. 400 breeding lines from Home Test.
4) Yield and quality results of c. 60 breeding lines tested in the Preliminary Test.
5) Yield and quality data of c. 30 breeding lines tested in the registration test.
6) Up to 2 oat lines supported for registration

Objective #2: Agronomic research to develop oat production guide
2018/2019: Data and summary of the 1st year Exp1.
2019/2020: 2nd year data pf Exp1 and summary across two years for Exp1
2020/2021: 3rd year data for Exp1, summary across years, crop guide on optimal N.
2021/2022: first year data of for Exp2 and Exp3
2022/2023: 2nd year data for Exp2&3 and final summary, production guide on N application and planting density.

Objective #3: Genomic selection
Each year starting from year 1 (2018/19):
-GBS markers for about 2000 new breeding lines (about 1000 from each of Ottawa and Brandon);
-900 lines from training population genotypes and phenotyped, added to database, and used to update GS predictions for both breeding programs.
-80 lines from each of Ottawa and Brandon selected based on GS and increased in New Zealand

Each year starting from year 2 (2019/20):
-80 GS-selected lines from each breeding program are tested in performance tests together with selections from regular breeding streams.
-Evaluation of the performance of GS breeding streams, and overall performance of breeding programs relative to common checks.

Objective #5: Crown rust survey (annually)

• Report on the crown rust rating of the oat crown rust differential lines tested in Ottawa and Morden
• Report Survey results of oat field in eastern Canada and western Canada
• Report of reactions of key oat cultivars and promising lines to different crown rust races

Objective #6: North American joint oat breeding and testing

• Yearly data of grain yield, agronomic traits, grain quality traits, and diseases for c. 240 new breeding lines from 4 breeding programs at 5 locations and compositional quality from at least one location.
• Genotypes and phenotypes of ENCORE incorporated to train and evaluate GS.

Objective #7: Oat Data and Knowledge Management

• 2018: Formal linkages and curational arrangements with T3/Oat, GrainGenes, ORI, and POOL.
• 2019: POOL is up-to-date with recent germplasm from major North American programs and queries in POOL provide a gateway to relevant data in T3/Oat and GrainGenes.
• 2020: Rust gene nomenclature is up-to-date and QTL survey is complete.
• 2021: Rust genes and QTL can be queried on the oat genome sequence to find candidate genes or develop better markers.
• 2022: Simple or advanced queries available for in-depth knowledge on Canadian oat varieties.
• 2023: Useful queries are available for breeders to interrogate germplasm from crop wild relatives.

RESULTS

Executive Summary

Due to the COVID-19 pandemic, some work was not done as planned. For Cultivar Development (Breeding): 1) the Hill nursery was not planted. Therefore, there will not be a normal Observation nursery in 2021. These negative effects will be carried to future years. 2) nurseries and trials at Ottawa were planted one month later than normal, which caused extremely low yield and seed production. Nevertheless, selections were made with the awareness that the results may not reflect the "normal" environment and the selection may not be completely meaningful. 3) No yield trials were conducted at the Normandin site. For Genomic Selection: 1) No Home Test was conducted at the Normandin site, which affects genomic selection (GS) model development to some extent; 2) GS was delayed by half a year and related yield trials will be delayed by one year. For Agronomic Studies: no experiments were conducted at the following locations: Normandin QC, Richardson sites (Winnipeg and Indian Head), Lacombe AB, and Beaverlodge AB. Amending plans were made for experiments in the years of 2021 and 2022.

Despite of the pandemic, we were able to release five new oat cultivars, three supported by Ontario Cereal Crops Committee (OA1444-5-19, OA1598-1, and OA1613-5) and two (OA1609-7 and OA1610-6) by RGCQ of Quebec. Among these OA14444-5-19 has superior levels of yield, groat, beta-glucan, test weight, and crown rust resistance and is most adapted to southern and eastern Ontario (mega-environment 1); the other lines are most adapted to the rest of eastern

Canada (mega-environment 2). Among the latter group OA1609-7 is a Quaker-preferred cultivar; it had small but important improvements over AAC Nicolas in maturity, yield, groat, kernel weight, and b-glucan.

Three GS lines selected from the 2017 Observation nursery yielded were tested in the Quebec registration trials in 2020. OA1652-3GS and OA1675-1GS yielded the highest cross 6 locations. OA1675-1GS also showed good levels of grain and nutritional quality and will be further tested in 2021. OA1652-3GS will be dropped due to exceptionally low kernel and test weight; it was used as a parent in the 2021 crosses, however. Several GS lines selected from the 2018 GS-VS head-to-head comparison yielded well in the 2019 Home Test and the 2020 Preliminary/ENC ORE Test. OA1692-4GS and several sister lines yielded extremely well at the prairie locations in 2020 but they will not be tested further due to poor kernel weight, test weight, and plumpness. A few other GS lines from this cohort will be tested in the 2021 Registration trials along with their VS sisters. GS with the Brandon breeding program also showed that GS lines tended to have defects in agronomic and/or grain quality traits.

The past two-years of N fertilizer rate study led to the preliminary conclusion that the maximum economic rate of N (MERN) was 100-160 kg/ha. depending on the locations and soil fertility.

Two useful papers have been published. One reports the results of mega-environmentt analysis which classified the oat growing regions in Canada into three major oat mega-environments. This provides a formal basis for strategic planning of oat breeding and genomic selection in Canada. The other paper reports a new method for determining the optimum number of replicates in multi-location crop variety trials. Applying this method to ORDC oat trials data showed that two replicates would be sufficient. Applying the method to OCCC performance trials for spring wheat, winter wheat, barley and oat also showed that two replicates would suffice for all four crops. The latter study led OCCC to reduce its required number of replicates from four to three, starting in the 2021 trials.

Summary by objective

Objective #1: Cultivar development (Yan, MacEachern, Morasse, Mountain, Nilsen, Hadinezhad, Tinker, Bekele)

- Five new oat cultivars were supported for registration, three by Ontario Cereal Crops Committee (OA1444-5-19, OA1598-1, AND OA1613-5) and two (OA1609-7 and OA1610-6) by RGCQ of Quebec. Among these OA14444-5-19 has superior levels of yield, groat, beta-glucan, test weight, and crown rust resistance and is most adapted to southern and eastern Ontario (mega-environment 1); the other lines are most adapted to the rest of eastern Canada (mega-environment 2). OA1609-7 is a Quaker-preferred cultivar; it had small but important improvements over AAC Nicolas in maturity, yield, groat, kernel weight, and b-glucan.
- 32 lines were tested in the ORDC registration trials and three promising lines were identified (OA1655-1, OA1655-2, and OA1658-1). 7 lines were tested in the Quebec registration trials and OA1570-5-5 and OA1675-1GS performed well and will be further tested.

- 66 lines, including some GS-selected lines, were tested in the Preliminary Test in conjunction with ENCORE. Many of these will be advanced to the registration test in 2021.
- 432 lines were tested in 2020 Home Test at three locations (Ottawa, New Liskeard, and Harrington PE). This test serves multiple purposes: to identify superior oat genotypes for release as new cultivars, to generate phenotypic data for GS model development, and to study the relative selection efficiency of GS versus visual selection. The Home Test assessed 60 visually selected lines from 2018 hills (VS), 60 genomics predicted high yielding lines (GS), and 20 genomics predicted low yielding (GC) from the same selected crosses.
- Five Observation nurseries were planted and visual selection was conducted.
- No hill nurseries were planted.
- About 70 new crosses were made in Jan 2021 (still in greenhouse); no new crosses were made in 2020.
- Greenhouse advance of new crosses was conducted year-round as usual.
- Certified Seed was produced by tendering companies for OA1453-2 (AAC Stature), OA1415-2 (AAC Excellence), OA1426-2 (AAC Clyde), OA1436-1 (AAC Roberval) and OA1444-4 (AAC Reid). AAC Excellence caught the attention of Quaker for its excellent yield, grain quality, beta-glucan, and groat levels.
- Breeder Seed was produced for OA1568-6 (AAC Chandler).
- Pre-Breeder seed was produced for OA1584-3, OA1594-1, and OA1609-7.

Objective #2: Agronomic research to develop oat production guide **(Ma,** Mountain**, Hall, Entz, Morasse, Leach, Kobuta, Semach)**

- A 3rd year N-study was conducted at 4 locations across Canada (Ottawa ON, New Liskeard ON, Melfort SK, and Yonkton SK) and useful results were obtained. Data on yield, agronomic traits, and nutritional quality traits have been collected.
- Results from preliminary analysis of 3 years of the data showed the following trends: 1) oat grain yield responded positively to increasing N rates at 10 site-years ($p \leq .001$); 2) there is strong positive correlation between yield and plant height for 11 of the 14 sites-years ($p \leq .001$). 3) the estimated most economic rates of N (MERN) for Ottawa, Melfort, Yorkton, Lacombe and Beaverlodge were 136, 148, 80, 110 and 141 kg N ha^{-1}, respectively, N being preplant application of urea. The estimated yield at MERN was 6315 kg ha^{-1} (Ottawa), 6420 kg ha^{-1} (Melfort), 3943 kg ha^{-1} (Yorkton), 7166 kg ha^{-1} (Lacombe), and 4891 kg ha^{-1} (Beaverlodge). No yield response was observed at New Liskeard and Normandin for all years, or the single year at Winnipeg.
- The MERN results of 136 kg ha^{-1} for Ontario and 148 kg ha^{-1} for Melfort, SK will be used for testing a split application strategy (Exp. 3) at 3 sites (Ottawa, New Liskeard and Melfort) in the 2021 growing season.
- For 2018-2019 (data for the 2020 samples to be incoporated) beta-glucan content of the 11 site- years where it was measured ranged from 3.7 to 5.2%. N treatments did not show a significant effect on beta-glucan content in 7 site-year environments. For the 4 environments that displayed a response, beta-glucan content increased in two cases, but was decreased in the other two cases, with increasing N application rates.
- At all sites in 2018 and 2019, percentage of groat and protein concentration both increased with increasing N.
- At maturity, oat plants accumulated on average more N than P, with a higher accumulation of both N and P in the grain than in the straw. In 2019, the mature plants

accumulated on aveage 109 kg ha^{-1} N and 29.7 kg ha^{-1} P with an N:P ratio of 5.5. In 2020 due to drought conditions, the yields at Ottawa, New Liskeard, and Yorkton were much lower than those in 2019, with mature plants taking up on average only 74 kg ha^{-1} N and 12 kg ha^{-1} P. The Ottawa site in 2020 had the lowest yields (841 kg ha^{-1}) and total N and P accumulation of all site-years, with only 40 kg ha^{-1} N and 7 kg ha^{-1} P accumulated in the mature plant (N:P ratio of 5.4).

- For most site-years, there was a very strong positive correlation between yield and both seed total N and plant total P accumulation (kg ha^{-1}).

Objective #3: Genomic selection (**Tinker, Bekele, Yan**)

- The Rapture based oat genotyping assay continues to perform well.
- GBS-Rapture marker assays were initiated for 3500 training and breeding lines.
- GS modelling and selection are both delayed this year due to restricted laboratory access, but genotyping is in progress at the time of writing and we plan to develop models and make selections in time to plant a pilot protein content germplasm enhancement set of lines in the 2021 field season. The standard yield and beta-glucan GS validation set from 2020 will be sent to New-Zealand for a seed increase together with 2021 GS and visual selections. GS selections from previous years are described above under cultivar development.

Objective #5: Crown rust test and survey (annually) **(Menzies, Xue, Yan)**

- 526 new oat lines tested in HT, Preliminary, and Registration trials were screened for crown rust resistance at Oxford ON and crown rust and smut resistance at Morden MB.
- Three oat fields located in Central 5, Central 8, and Central 9 on the Central Experimental Farm (CEF) in Ottawa, Ontario were monitored for the occurrence and severity of diseases during the growing season in 2020. Of the nine diseases observed, barley yellow dwarf (BYDV), crown rust, halo blight and stem rust were the most prevalent, having moderate to severe levels of infection in 3, 2, 2, and 2 fields, respectively. Fusarium head blight (FHB) was observed in all three fields with low severities. *Fusarium sporotrichioides* and *F. equiseti* were the predominant species isolated from the FHB infected kernels.

Objective #6: North American joint oat breeding and testing (**Yan, Nilsen, Beattie, Hadinezhad**)

- 180 oat lines from three breeding programs were tested at Ottawa ON, Brandon MB, Lacombe AB, and Saskatoon SK. Data of grain yield, agronomic traits, grain and nutritional quality traits, and diseases were obtained at 4 all locations (Ottawa ON, Brandon MB, Lacombe AB, and Saskatoon SK). The data were shared with all breeding programs and the genomic selection group.

Objective #7: Oat Data and Knowledge Management **(Wight)**

- Participation in weekly conference calls with the T3/Oat and GrainGenes teams (USDA-ARS) continues.
- The new version of the T3/Oat database (https://oat.triticeaetoolbox.org/) is now live, and the data from the original POOL database have been transferred there. Approximately 350 lines still have issues that need to be resolved. Breeders will soon be asked to send their more recent pedigree data.

- Sixty-three more classical and molecular genetic maps were uploaded to GrainGenes (https://wheat.pw.usda.gov/).
- An MS Access database was created to hold all of the information regarding mapped oat genes, QTL (Quantitative Trait Loci), and RGAs (Resistance Gene Analogues). It currently contains information for 3465 markers associated with 1681 genes, QTL, and RGAs. There is still some work to do to populate the database and complete the comparative mapping before a decision is made regarding how to make the data accessible *via* GrainGenes.

Issues

- Describe any challenges or concerns in achieving the results and deliverables of this activity during the reporting period. How were they overcome or how do you plan to overcome?
- Describe any potential changes to the work plan and the budget during the reporting period. How were or how will they be managed?

1. The COVID-19 pandemic caused cancels of planned work at several locations, delayed planting at some locations, and reduced work at almost all centers have affected the output this year and probably in future years. Although some measured have been taken to minimize the influence, the damage will not be fully covered. Luckily since we have a healthy breeding pipeline, the release of new cultivars in future years will not be affected.
2. With the new knowledge that the Canadian oat growing regions consist of three major mega-environments (ME), our testing strategy should be adjusted to 1) testing nationally in the preliminary test to understand the specific adaptation of breeding lines and 2) to test advanced lines in their specially adapted mega-environments. This would allow ORDC to breed for all three mega-environments. Likewise, western breeding programs can do the same if ENCORE is expanded to include locations in Normandin QC, Harrington PE, Elora ON, and New Liskeard ON. ENCORE 2.0 and GS 2.0 may be developed from this idea.
3. Three cohorts of GS showed that 1) GS prediction for yield is generally successful in the targeted area; 2) high yielding lines tended to be poor in agronomic and grain quality traits. Therefore, it is necessary to modify our way to do GS by incorporating other key breeding objectives or by combining visual selection for other traits. The latter approach should be cheaper and can combine the merits of both breeder's visual selection and genomic selection.

Key Achievements

A key achievement represents a significant achievement or tangible result that could potentially be applied either by farmers or industry or the science community. In one to three paragraphs, please provide key achievements that meet one of the following criteria:

1) The item has commercial potential (all testing and piloting has been completed);
2) The item has been commercialized; or
3) The item has been adopted by the sector.

Examples of tangible results could include increased sustainability (beneficial management practice), reduced costs, improved productivity or increased profitability. Please note that the information provided will be used for communication purposes only.

If no key achievements have been realized at this stage, please leave this section blank.

1. Five new oat cultivars (OA1444-5-19, OA1598-1, OA1613-5, OA1609-7, OA1610-6) have

been released; two of these have been taken by SeCan in Feb 2021

2. Two genomic-selected lines (OA1652-3GS, OA1675-1GS) yielded very well in the Quebec provincial trials, OA1675-1GS will be further tested in 2021 for possible release as a new cultivar. Several GS lines selected in 2019 will be tested in the 2021 Registration trials, along with their VS sisters.
3. The cultivar AAC Excellence released in 2019 had captured the attention of Quaker for its superior yield, b-glucan, groat, test weight, and kernel weight in Quebec and the Maritimes. It is the best cultivar when all these traits are considered.
4. The N rate study so far led to a firmer conclusion on the maximum economic rate of N across Canada.
5. Mega-environment analysis led to the understanding that the oat growing regions in Canada into three oat mega-environments (Crop Science, 2021): ME1 = areas 2 and 3 in Ontario, ME2 = Quebec, Maritimes, and northern Ontario, and ME3 = Canadian Prairies. This sets a basis for strategic planning for oat breeding and genomic selection in Canada.
6. A novel method to determine the optimum number of replications in multi-location crop variety trials were developed and published (Frontiers in Plant Science, Jan 2021). Applying this method to OCCC data led OCCC to reduce the required number of replicates in the cereal crop trials from 4 to 3.